JOURNAL
OF
AMERICAN CONCRETE INSTITUTE

VOL. III JUNE, 1915 NO. 6

CONTENTS

PART I—Institute Affairs PAGE

Officers ... 2
Editorial ... 3
New Members ... 5
Reduced Price for Back Volumes ... 5
Membership Certificate ... 6
List of Standards ... 7
Synopses of Recent Articles ... 8

PART II—Proceedings Eleventh Convention

[Forming Part of Volume XI of Proceedings]

Contractor's Equipment, Austin Nichols Warehouse, by T. Arthur Smith ... 271
Mechanical Plant for Handling Concrete, by William P. Anderson ... 284
Concrete Forms for the Catskill Aqueduct, by Alfred D. Flinn ... 291

PUBLISHED AT THE OFFICE OF THE INSTITUTE
1418 WALNUT STREET, PHILADELPHIA, PA.

SINGLE COPIES, $.50 PER YEAR, $5.00

Copyright, 1915, by the American Concrete Institute

OFFICERS

President

LEONARD C. WASON
(Term expires 1916)

Vice-Presidents

HENRY C. TURNER
(Term expires 1916)

WILLIAM K. HATT
(Term expires 1917)

Directors

EDWARD D. BOYER
WILLIAM H. HAM
JOHN B. LEONARD
(Term expires 1916)

WILLIAM P. ANDERSON
ERNEST ASHTON
ALFRED E. LINDAU
(Term expires 1917)

Past President

RICHARD L. HUMPHREY

Secretary

CHARLES L. FISH
(Term expires 1916)

Treasurer

ROBERT W. LESLEY
(Term expires 1916)

President, Secretary and Treasurer elected for one year, Vice-Presidents and Directors, for two years.

Executive Committee

Leonard C. Wason
Edward D. Boyer
Charles L. Fish
Robert W. Lesley
Henry C. Turner

STANDING COMMITTEES

Publications and Papers

Richard L. Humphrey, *Chairman*
William H. Ham
Robert W. Lesley
William K. Hatt
Henry H. Quimby

Finance

Leonard C. Wason, *Chairman*
Robert W. Lesley
Henry C. Turner

PURPOSE OF THE INSTITUTE

It is the purpose of the Institute, by means of conventions and publications, to increase and disseminate knowledge in regard to the use of cement, concrete and allied products; to conduct research into their properties and uses; and to formulate recommended practice and standard specifications.

Its objects are purely educational.

JOURNAL
OF
AMERICAN CONCRETE INSTITUTE

FOUNDED 1905, AND INCORPORATED 1906, AS
NATIONAL ASSOCIATION OF CEMENT USERS
CHARTER AMENDED JULY 2, 1913

The Institute is not responsible, as a body, for the statements and opinions advanced in its publications

VOL. III JUNE, 1915 NO. 6

THE PRESIDENT'S POINT OF VIEW.

The concrete industry has grown rapidly into one of the most important branches of American constructional activities. We are justly proud of this phenomenal progress, but those of us who have grown up with the industry during its quarter century of development, realize that it is not yet well knit together. So long as the individuals pull apart, intentionally or unknowingly, each of us lacks the support of the industry as a whole.

No collective progress has been made in a great industry until the individuals became well acquainted. The demand for the product of the industry may produce flourishing conditions temporarily, but the stress of hard times will find no united intelligent organization to combat threatened demoralization during a period of business depression.

Our industry is a peculiar one. Our product is manufactured very largely in exposed situations, without the facilities and shelter of the mill or shop housing the average manufacturing industry. Much of our labor is unskilled and requires careful oversight, for few men appreciate fully all the essential requirements for good, reliable concrete. As an engineer, I can also say, without disparagement to my profession, that designers do not always appreciate all the field requirements for good work and the economical use of their clients' funds. Better general study of technical needs of our industry is highly desirable.

When an industry flourishes collectively, its individuals are most successful. In our industry the American Concrete Institute offers the best opportunity for us to bring about this consolidated forward march. We have our business problems arising out of our relations with each other as designers, builders, and producers of materials and machinery needed in our work. We have our technical problems, which, if improperly answered, result in failures that hurt the business of every one of us. We must endeavor to find the right solution of each of our technical problems and then spread the knowledge of it broadcast.

Individually we can accomplish comparatively little; collectively we can become a powerful influence. I believe that each of us in this industry will be more proud of his part in it as the industry itself becomes stronger, more independent and more respected. So I ask each member who is a contractor to make it a personal matter during the next fortnight to send in an application for membership from at least one of his most active competitors, so we may strengthen our standing as a business organization, and I ask each member in any branch of the industry to send the application of at least one architect, engineer or superintendent, so we may have the technical strength which will make our views of weight in professional circles.

LEONARD C. WASON.

New Members.

The following new members have been elected:

KANSAS STATE AGRICULTURAL COLLEGE, R. A. Seaton, Professor of Applied Mechanics, Manhattan, Kansas.

MUNICIPAL REFERENCE LIBRARY, Franklin F. Stopper, Chief of Order Department, Municipal Building, New York City.

NATIONAL FIREPROOFING CO., Philip H. Bevier, Superintendent of Construction, Flatiron Building, New York City.

SAGENDORFH CO., INC., THE, Frank E. Sagendorph, 2d, President, 131–133 S. 24th St., Philadelphia, Pa.

SCOTT, ALEXANDER, Cangallo 564, Buenos Aires, Argentine Republic.

STANDARD OIL CO. OF NEW JERSEY, Charles H. Haupt, Chief Engineer, P. O. Box 16, Elizabeth, N. J.

Reduced Prices for Back Volumes.

Members of the Institute can obtain copies of back publications at the following special prices:

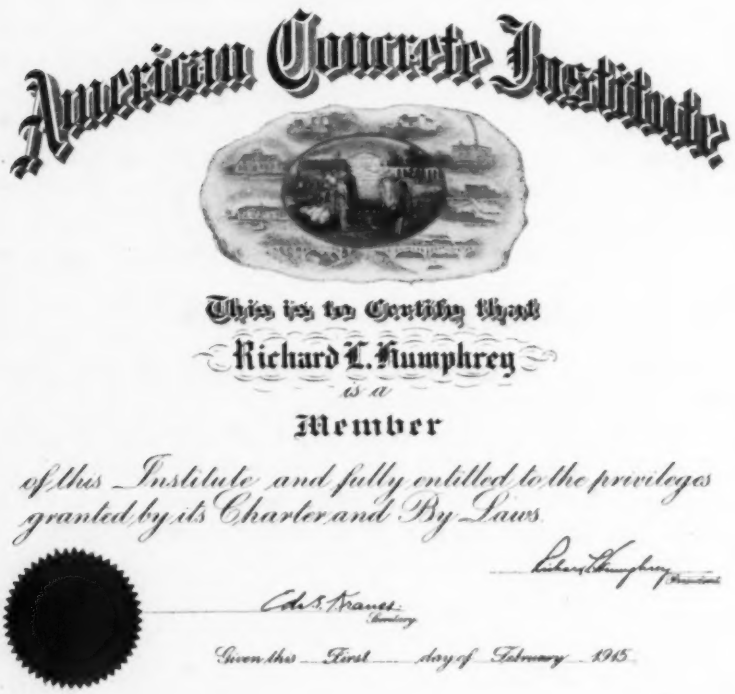
Vol. I, 50 cents; Vols. II to VI, $1.50 each; all in paper binding. For cloth or half morocco binding there is an additional charge per volume of 50 cents or $1.00 respectively. Vol. VII is available only in cloth binding, $2.00, or half morocco, $2.50.

Membership Certificate.

A Certificate of Membership in this Institute will be furnished to any member in good standing, i. e., whose dues are paid up to date. These Certificates are printed from an engraved steel plate. The name of the member is engrossed and the Certificate will be signed by the President and Secretary. The Certificates are about 10 x 14 ins., and have sufficient margin to be framed 14 x 17 ins. They are engraved on parchment or parchment paper, both suitable for rolling or framing.

The charge for certificates is as follows:

Parchment	$2.50
Parchment Paper	1.50


American Concrete Institute
This is to Certify that
Richard L. Humphrey
is a
Member
of this Institute and fully entitled to the privileges granted by its Charter and By Laws
Given this First day of February 1915

MEMBERSHIP CERTIFICATE.

Standards Adopted by the Institute.

1. Standard Specifications for Cement with Appendix on Standard Methods of Testing and Chemical Analysis, 23 pp.
2. Standard Specifications for Portland Cement Sidewalks, 6 pp.
4. Standard Building Regulations for the Use of Reinforced Concrete, 13 pp.
5. Standard Specifications for One Course Concrete Highway, 10 pp.
6. Standard Specifications for Portland Cement Curb and Gutter, 7 pp.
7. Standard Recommended Practice for the Use of Reinforced Concrete, 21 pp.
8. Standard Specifications for Scrubbed Concrete Surfaces, 3 pp.
9. Standard Recommended Practice for Concrete Drain Tile, 3 pp.
10. Standard Recommended Practice for Concrete Architectural Stone, Building Block and Brick, 4 pp.
11. Standard Specifications for Concrete Architectural Stone, Building Block and Brick, 3 pp.
12. Standard Building Regulations for the Use of Concrete Architectural Stone, Building Block and Brick, 3 pp.
13. Standard Specifications for Plain Concrete Floors, 6 pp.
14. Standard Specifications for Reinforced Concrete Floors, 5 pp.
15. Standard Specifications for Portland Cement Stucco on Metal Lath, Brick, Tile or Concrete Block, 9 pp.
16. Standard Methods for the Measurement of Concrete Work, 7 pp.
17. Standard Specifications for One Course Concrete Street Pavement, 10 pp.
18. Standard Specifications for Two Course Concrete Street Pavement, 11 pp.
19. Standard Specifications for One Course Concrete Alley Pavement.

The above Standards can be obtained at the price of 25 cents each or in lots of ten or more at 20 cents each. Special price to Members 15 cents or 10 cents each in lots of ten.

Synopses of Recent Articles on Concrete.

Reviewed May 1 to 31, 1915.

The synopses given below are for the purpose of keeping the members of the Institute in touch with the leading articles of interest appearing in the many technical journals and are not complete reviews of these journals. The publications regularly reviewed appear below and the number given corresponds to the number following the title of the paper. The length of the article in pages, whether illustrated or not, is noted, and the publications reviewed in which it appears:

1. Canadian Engineer, Toronto, Ontario, Canada.
2. Cement, New York, N. Y.
3. Cement and Engineering News, Chicago, Ill.
4. Cement Era, Chicago, Ill.
5. Cement World, Chicago, Ill.
6. Concrete Age, Atlanta, Ga.
7. Concrete Era, Los Angeles, Cal.
8. Concrete-Cement Age, Detroit, Mich.
9. Concrete and Constructional Engineering, London, England.
10. Engineering and Contracting, Chicago, Ill.
11. Engineering News, New York, N. Y.
12. Engineering Record, New York, N. Y.
13. Good Roads Magazine, New York, N. Y.
14. Portland Cement, Kansas City, Mo.
15. Rock Products, Chicago, Ill.
16. Proceedings American Railway Engineering Association, Chicago, Ill.
17. Western Contractor, Record Building, Kansas City, Mo.
18. Journal National Fire Protection Association, Boston, Mass.
19. Journal Western Society of Engineers, Chicago, Ill.
20. Proceedings American Society of Civil Engineers, New York, N. Y.
21. Proceedings American Society of Municipal Improvements, New York.
22. Proceedings American Society for Testing Materials, Philadelphia, Pa.
23. Proceedings Engineers' Club of Philadelphia, Philadelphia, Pa.
24. Proceedings Engineers' Society of Western Pennsylvania, Pittsburgh, Pa.
25. Professional Memoirs, Corps of Engrs., U. S. A., Washington, D. C.
26. Proceedings Institution of Civil Engineers, London, England.
27. Transactions, Canadian Society of Civil Engineers, Montreal, Quebec, Canada.
28. Railway Age Gazette, Chicago, Ill.
29. Better Roads, Jamestown, Ohio.

MATERIALS

General Practice in Sand Testing. (13) May, 1¼ pp. Outfit and methods used in Denver laboratory—requirements for acceptance by Board of Water Supply of New York.

Use of Six-Inch and Eight-Inch Aggregate Points to Economies in Concrete Work, by Edward O. Keator. (13) May, 2 pp. Is cheaper than smaller sizes and when machine mixed produces a stronger concrete—no difficulty is found in handling mixture.

Direct Control Over Construction Materials is Feature of 100-Mile Winnipeg Aqueduct. (13) May, 2¼ pp., ill. Six communities, forming water district, build construction railroad, supply all cement and deliver to work properly graded mixture of sand and gravel.

Economics of Concrete Construction, by DeWitt V. Moore. (10) May, 5 pp.

Testing and Handling Concrete Aggregates, by H. S. Mattimore. (10) May, 1¾ pp., ill.

Standard Apparatus and Procedure Recommended for Sand Analysis. (13) May, 2¼ pp.

DESIGN AND TESTS

Arched Reinforced-Concrete Conduits Designed by the Theory of Least Work by Walter M. Smith. (13) May, 4 pp., ill. Complete solution for a large conduit subjected to high earth pressure by use of graphical methods and tabular computation.

Problems in the Theory of Construction, by Ewart S. Andrews. (9) May, 3 pp., ill. A semi-circular arch carrying its own weight only.

BUILDINGS

An All-Concrete Barn, by E. S. Fowler. (3) May, 3½ pp., ill. The details of design and construction of a permanent farm barn.

G. T. R. Windmill Point Elevator Annex, Montreal. (1) May, 1 p., ill. Description. Vagaries of changes in length, due to variations in temperature, are disclosed in tests on structure in Cambridge, Mass. (13) May, ¾ p., ill.

Design and Construction Features of the Palmer Memorial Stadium, Princeton, N. J. (11) May, 3¼ pp., ill. Stadium has seating capacity of 41,527.

Factory with Down Ventilation Through Columns. (12) May, 1 p., ill. Details of building with hollow-concrete-and-steel columns, eliminating all complications as to the distributing ducts.

Reinforced Concrete in Earthquake Districts. (9) May, 5½ pp., ill. Regulations by the Ministry of Public Works, Rome.

New Works in Concrete at Home and Abroad. (9) May, 5 pp., ill.

HOMES

Model Farm Bungalow, by Charles A. Byers. (5) May, 3½ pp., ill. Plans and views of concrete home.

BRIDGES AND RAILROAD WORK

The Construction of the Mount Royal Tunnel for the Canadian Northern Railway, by J. L. Busfield. (10) May, 1¾ pp., ill. Showing details and methods of construction.

Concrete Viaduct of a New Type; Eastern Viaduct, New York Connecting R. R. (12) May, 2 pp., ill. Details and description.

A Series of Reinforced-Concrete Cantilevers in the Form of Arches. (12) May, 2¼ pp., ill. Details and construction.

Some Data on the Design and Cost of Concrete Piles Used on Railroad Work. (11) May, 1¼ pp., ill.

The Designing of Reinforced Concrete Slabs Subjected to Bending and Compression, by Anders Bull. (11) May, 2½ pp., ill.

Design and Construction of the Langwies Viaduct—Chur-Arosa R. R., Langwies, Switzerland, by Albert M. Wolf. (6) May, 6¼ pp., ill. Details and description of huge structure. Unique method of centering.

Concrete Bridge Built in Installments, by Dr. Edward P. Bailey. (5) May, 4 pp., ill. Details of a structure in Washington, D. C., in which the future growth of traffic was discounted.

Ornamental Fence and Retaining Wall. (5) May, ¾ p., ill. Interesting details of reinforced-concrete construction on a railway property line in Milwaukee, Wis.

Concrete Floors for Steel Bridges. (5) May, 4 pp., ill. Details of design and construction of several standard types of solid reinforced concrete floors for plate girder and truss spans.

RESERVOIRS DAMS CANALS ETC.

Fallsway Viaduct in Baltimore Built on Sharp Curve with Concrete from 205-Foot Tower. (13) May, 2¾ pp., ill. Ribbed-arch structure in the Jones Falls improvement supported above concrete conduit and poured from high central towers served by a single mixing plant.

Experimental Mississippi River Levees Indicate Possibility of Eliminating Seepage, by Major C. O. Sherrill. (13) May, 1¾ pp. ill. Embankments faced with concrete and provided with sheet piling at toe stop flood waters that penetrate larger dikes of standard design.

Indianapolis Builds Million Dollar Storm-Water Drain Under Railroad Yards. (13) May, 1¼ pp., ill. Huge double-box section, preliminary to track elevation, constructed by movable concrete outfits operating at both ends of the work.

Repairing and Waterproofing the Nashville Water-Works Reservoir, by W. W. Southgate. (12) May, 4 pp., ill. The interior face of the old and new wall was waterproofed with cement-gun plaster.

An Unusual Dam, by Sylvester Q. Cannon. (12) May, ½ p., ill. Description of a small hollow reinforced concrete dam.

The Duxbury Reinforced-Concrete Water-Works Tank. (12) May, ½ p., ill. Showing structural details of tank 40 ft. diameter and 35 ft. high.

Concrete Viaduct of a New Type; Eastern Viaduct, New York Connecting R. R. (12) May. 2 pp., ill. Description and details.

Baltimore Filters Abound in Useful Hints on Concrete Construction and Design, by James W. Armstrong. (13) May, 3½ pp., ill. Wet concrete hindered screeding on slopes—steel forms at first caused trouble, but gave satisfaction when remodeled—cypress strips used at joints.

Protecting River Banks Against Floods. (4) May, 2½ pp., ill. Description of concrete paving as protection against the erosion of river banks.

Constructing Reservoir and Pipe Line in an Arizona Town. (4) May, 1½ pp., ill. Description of reservoir 157 ft. in diameter, 17 f'. high and 4½ miles of reinforced concrete pipe line.

Design and Methods and Cost of Constructing the Los Angeles City Trunk Line, Connecting Aqueduct to Distribution System, by Burt A. Heinly. (11) May, 3½ pp., ill.

The Duxbury Reinforced-Concrete Water-Work Tank. (12) May, ¾ p., ill. Shows constructural details.

Slope Protection—New Welland Ship Canal, by Eric P. Muntz. (1) May, 2 pp., ill. Description of concrete slab wash-wall.

Methods of Plaster Lining Irrigation Canals and Laterals, Okanogan Project, U. S. Reclamation Service. (11) May, 2 pp.

Direct Control Over Materials a Feature of the Winnipeg Aqueduct. (10) May, 2¾ pp., ill. Six communities, forming water district, build construction railroad, supply all cement and deliver to work properly graded mixture of sand and gravel.

Kensico Dam Construction in 1914, by Wilson F. Smith. (12) May, 3 pp., ill.

Multiple-Arch Diversion Dam at Three Miles Falls, Oregon, by H. D. Newell. (12) May, 3½ pp., ill. Design and construction details.

Hollow Reinforced-Concrete Structure Replaces Dam at Austin, Texas, which failed Fifteen Years Ago. (13) May, 2 pp., ill. Part 1—which reviews history of previous dam and describes work for rendering seamy rock impermeable. Cut-off trench grouted after compressed air tests.

Design and Construction of the North Side Reservoir of the Pittsburgh Water Works. (6) May, 4 pp., ill.

Building Concrete Drops on Irrigation Canals in Western Canada, by Robert S. Stockton. (6) May, 3 pp., ill. Description and costs.

Memphis Flood Protection, by Ray L. Defried. (5) May, 3½ pp., ill. Two immense concrete tunnels, sixteen feet in diameter and over a mile in length, now being constructed at a cost of $517,000, to drain the Mississippi River overflow from the streets of Memphis, Tenn.

Reinforced Concrete Quay Wall, Southampton, by J. A. Crowther. (9) May, 4 pp., ill. Design and description.

ROADS AND PAVEMENTS

Concrete Paving between Street Car Rails in Minnesota, by Stanley E. Bates. May, 2 pp., ill. Showing details of construction and drains.

The Highway Engineer and His Relation to Standards and Culvert Design, by Preston L. Jones. May, 2½ pp., ill.

Some Methods and Costs of Concrete Pavement Construction at Des Plaines, Illinois, by M. P. Taylor. (11) May, 1¾ pp., ill.

Study of a Water Supply by Pumping for Concrete Road Construction. (1) May, 5 pp., ill.

Lincoln Highway in Northern Indiana, by Sherrod K. Vaughn. (5) May, 2½ pp., ill. What the Hoosier State is doing toward construction of the great memorial trans-continental road and its tributaries.

SEWERS, PIPE, TILE, ETC.

Reinforced Concrete Standpipe, by W. G. Kirchoffer. (4) May, 2 pp., ill. Description, cost and method of construction.

Concrete Pipe for Culvert Purposes, by Charles P. Stivers. (4) May, 2 pp., ill.

Sewage-Treatment Plant at Calvert, Tex., by Thomas L. Fountain. (12) May, 5 pp., ill. Design and construction.

Reinforced-Concrete Pipes Replace Girder Bridge. (13) May, ½ p., ill. Three 6-foot lines form satisfactory substitute for street structure on Pennsylvania Railroad near Newport, Delaware.

MISCELLANEOUS

Concrete Storage Bins. (3) May, ¾ p., ill. Description of sand and stone storage bins.

Form Work Specified in Detail. (4) May, 2 pp., ill.

Experiences Gained from Reinforced-Concrete Barges Built for the Panama Canal, by W. Rowland. (13) May, 2¼ pp., ill. Failures in 1911, due to use anticipated in the design, do not prove unsuitability of the type. Extreme care needed in launching.

Advantages and Disadvantages of Reinforced Concrete, by Percy J. Waldram. (5) May, 3 pp. A candid survey of the structural functions and limitations of this modern building material.

Concrete on the Farm. (5) May, ¾ p., ill. Description of various uses of concrete.

Reinforced Concrete Pier ar Padstow, by Sir G. Croydon Marks. (9) May, 7 pp., ill. Details and description.

PART II.

PROCEEDINGS ELEVENTH ANNUAL CONVENTION.

Papers, Discussions and Reports.

CONTRACTORS' EQUIPMENT, AUSTIN NICHOLS BUILDING.

By T. Arthur Smith.*

Economy in the successful erection of reinforced concrete buildings is dependent on the efficiency with which the materials entering into the construction are handled upon delivery at the building site. The comparatively small yardage of concrete in any one building operation does not justify an elaborate and costly installation of receiving and mixing machinery. Inasmuch as even a large building operation seldom requires the use of the concrete plant more than four or five months, it is essential that the erection and removal of this plant shall be performed easily, quickly and cheaply. Its cost must be divided among several contracts and hence prompt transfer from one contract to another is of utmost importance.

In order that varying conditions on different buildings may be met, it is desirable that simple standards of plant layout be adopted. When a special installation is considered necessary, it is desirable before determining on a final layout to reduce the installation to a cost per cubic yard of concrete. This very often shows that the saving in the handling of materials is not sufficient to offset the cost of this special installation. Also, in special layouts, the labor of erection and removal is usually high and the bulk of the cost of materials entering into this installation should be charged largely to this one contract, as, after using once, it may be some time before a similar installation is required and plant depreciates rapidly.

Careful study must be given to the layout of all plants to be sure that it will fulfill all requirements. It must handle the total concrete yardage, without overloading, in the time allowed by the speed schedule and should have the capacity for so-called "big days"—days when conditions of the work call for maximum output.

* General Superintendent, Turner Construction Co., New York City.

AUSTIN NICHOLS BUILDING.

The Austin Nichols building (Fig. 1) is situated at the northwest corner of Kent Avenue and North Third Street, Borough of Brooklyn, New York City. It extends from Kent Avenue along North Third Street to the bulkhead line of the East River. The Austin Nichols Company, manufacturing wholesale grocers, occupy the entire building.

The contract for the erection of the Austin Nichols Building

FIG. 1.—AUSTIN NICHOLS BUILDING, COMPLETED SEPTEMBER 1, 1914.

was awarded December 12, 1913, and called for entire completion September 1, 1914. Failure to deliver the building complete by this date would subject the contractor to a heavy penalty. The building in plan is 440 ft. 0 in. x 178 ft. 8 in., 6 stories and basement in height. Floors are of beam and girder type construction. General layout of building is shown in Fig. 3.

The following list of materials entering into the building is chosen in order to give an idea of the size of the operation and the quantities of materials to be handled:

Excavation	24,200 cu. yds.
Piles (west half of building supported on piles)	2,520 " "
Cement	43,600 bbls.
Sand	16,920 cu. yds.
Gravel	21,000 " "
Cinders	2,800 " "
Reinforcing steel	1,560 tons.
Tile for partitions	128,000 sq. ft.
Granolithic finish (placed on 2½ in. cinder concrete base)	447,000 " "
Plaster (office partitions, fifth floor)	7,560 sq. yds.

FIG. 2.—SITE AUSTIN NICHOLS BUILDING, FEBRUARY 2, 1914.

This contract also included all subcontract work, the main items of which are as follows:—Structural steel (over tracks, first story), elevators, sprinklers, heating, plumbing, electric wiring, pneumatic tubes, refrigeration, spiral chutes and conveyors, roofing and waterproofing. The total cost of all subcontract work was $340,000.00.

The excavation, piling and concrete foundations were prosecuted during December, 1913, and January, February and March, 1914.

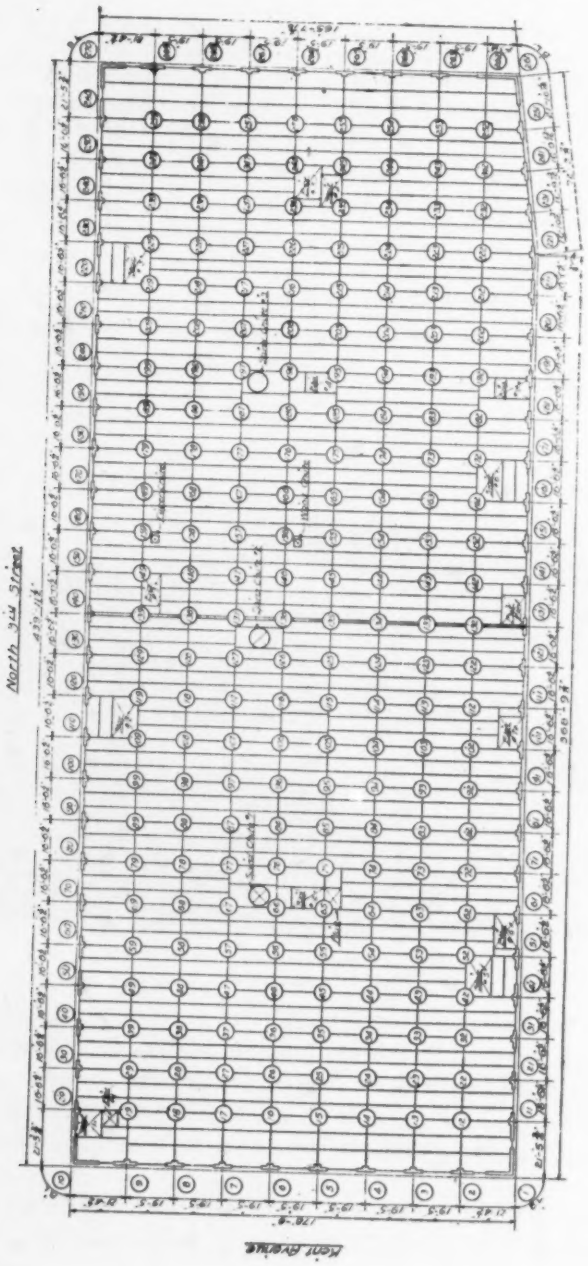


FIG. 3.—TYPICAL FLOOR PLAN.

For concreting foundations, a motor driven mixer, of ½ cu. yd. capacity, was set up west of the center of the building on North Third Street, the level of the street at this point being about 8 ft. above the general excavation level. The concrete was discharged into a box, from which it was wheeled in concrete carts, of 6 cu. ft. capacity, to the footings. Adjacent to this mixer was placed a vertical boiler of 25 H. P. capacity, the steam from which was used to heat water for the concrete, and to thaw out frozen sand and gravel. Over each footing concreted in freezing weather was placed a collapsible frame work, covered with heavy burlap, inside of which was placed a salamander burning coke. This method of preventing the concrete from freezing proved entirely satisfactory and made it possible to concrete regardless of temperature. This mixer was used while the excavation, piling, pumping, etc., interfered with the erection of the permanent concrete plants.

Serious difficulties were encountered in excavation, and driving of piles, due to the presence of old brick and concrete foundations, cribs, etc.; also, severe cold and heavy snow storms in February materially delayed the progress of excavation and piling, hence holding up the concreting of foundations. (Fig. 2.) Piling was completed April 7, 1914; excavation, April 7, 1914; foundations, April 11, 1914.

To entirely complete the building by September 1, 1914, required that the roof be finished by July 1st, and all concrete work, excepting cement floors, be completed by July 15th. This required the placing of 19,620 cu. yds. prior to July 15th.

The general layout of all plant used in the erection of the building is shown in Fig. 4.

UNLOADING AND CONCRETE EQUIPMENT.

The layout of the unloading derrick, storage bins, concrete mixers and hoists is shown in detail in Fig. 5 and Sections A–A, B–B, C–C. (Fig. 6.) Sand and gravel were delivered alongside the bulkhead, adjacent to the storage bins on scows of about 400 cu. yds. capacity. A derrick equipped with a clam shell bucket of 1⅝ cu. yds. capacity unloaded these scows into storage bins holding 100 cu. yds. of sand and 200 cu. yds. of gravel. This derrick is shown in Fig. 5 and Section B–B.

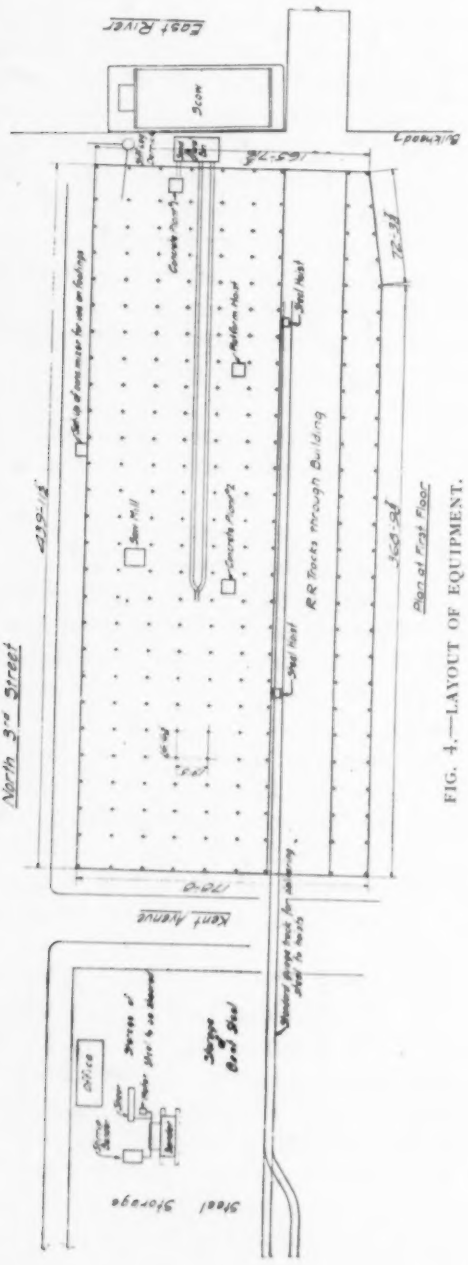


FIG. 4.—LAYOUT OF EQUIPMENT.

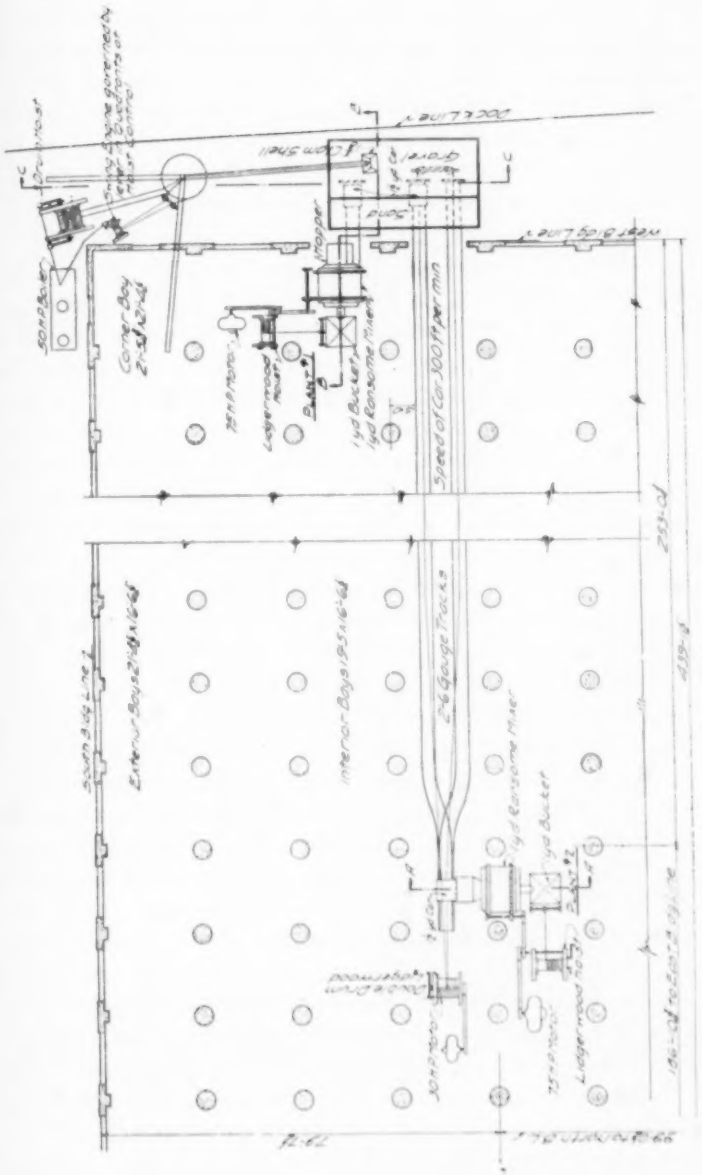


FIG. 5.—UNLOADING, MIXING AND HOIST EQUIPMENT.

It was operated by a three drum standard hoisting engine; cylinders 9 x 10 in., nominal H. P. 35. For swinging the derrick a separate engine was installed. Power was supplied by 50 H. P. horizontal boiler.

The sand and gravel were discharged from the bins through gates, into "V" bottom, two way dump cars for delivery to the mixers. Each car was loaded with 12 cu. ft. of sand and 24 cu. ft. of gravel, a steel partition separating these materials.

One car was used to convey this material to Mixer No. 1, and was pushed by hand from the storage bin to the mixer. For charging Mixer No. 2, a double track of 2 ft. 6 in. gage was laid from the bin to the mixer, on which 2 cars were operated, one on each track. These tracks were laid on the first floor, which, in order to follow the grade of North Third Street, sloped down 8 ft. from Kent Avenue to the river. A double drum hoist, motor driven, pulled the cars from the bin to the mixer. These cars were connected by a tail line operating around a sheave at the bin, so that the loaded car going toward the mixer would pull back the empty car to the bin.

Owing to limited bulkhead space at the building, it was necessary to dock the cement lighters one block away and truck the cement to the building. Cement was stored adjacent to each mixer. Six bags were used in each batch.

Two mixers were installed in the locations shown on Fig. 5. Each had a capacity of 1 cu. yd. of concrete per batch. Each mixer discharged into a bucket 1 cu. yd. capacity, which was hoisted by a single drum hoist. Power for the operation of each concrete plant was furnished by a 75 H. P. motor. Concrete was dumped from the bucket into a box on each floor holding 2 cu. yds., from which it was wheeled in concrete carts.

The use of spouts for placing concrete was carefully considered. Records of the cost of wheeling concrete on similar buildings showed that this cost did not exceed $.09 per cu. yd. This is based on labor at $.375 per hour doing this work. Assuming that of the 19,620 cu. yds. of concrete to be placed, 16,000 cu. yds. could be placed by spouting, the cost of wheeling saved by this spouting would be $.09 x 16,000 equal $1,440.00. Hence $1,440.00 would have to cover the cost of installing 2 spouting outfits and the following additional installations incidental to

placing concrete in this manner:—Raising tower additional height, guying tower, moving spouts. This analysis showed conclusively that, for this building, the cost of the spouting equipments, plus the additional installation cost, would materially exceed the cost of wheeling concrete.

EQUIPMENT FOR HANDLING REINFORCING STEEL.

The general layout of the steel yard and equipment is shown in Fig. 4. Steel was delivered in cars on the track adjacent to the steel yard. In unloading care was taken to place in separate piles all steel to be bent.

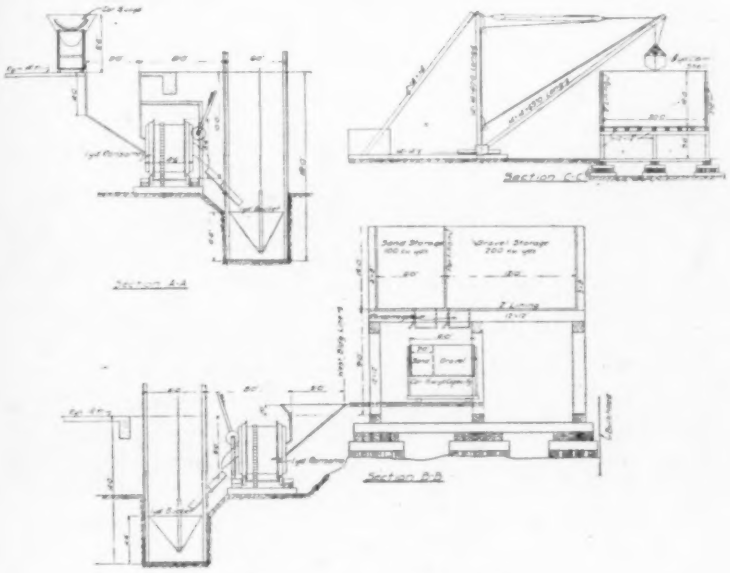


FIG. 6.—SECTIONS OF EQUIMENT.

The equipment installed in the steel yard consisted of 1 bender, for bending beam and girder bars, 1 stirrup bender and 1 shear, capable of shearing 1 in. square bars, all driven by one 15 H. P. motor. As the steel was required at the building, it was placed on standard gage hand cars, and pushed to the steel hoists. (See Fig. 4.) The 2 hoistways—4 ft. 6 in. x 4 ft. 6 in.—were placed as shown and sheathed on all sides with 2 in.

plank. Over each hoistway, on the floor in course of construction, was placed a gin pole 25 ft. 0 in. long, to which was attached the tackle, in order that the steel could be hoisted vertically. The hoisting was done by single drum motor driven hoists, one located adjacent to each hoistway on first floor.

The cement floors throughout the building consist of a top coat of cement mortar $\frac{3}{4}$ in. thick, placed on a cinder concrete base $2\frac{1}{2}$ in. thick. The cement mortar and cinder concrete base

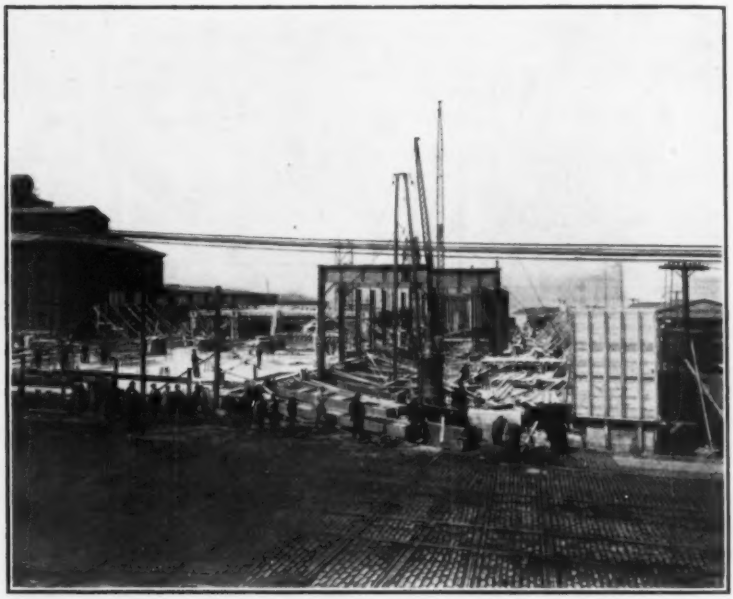


FIG. 7.—AUSTIN NICHOLS BUILDING, APRIL 17, 1914. FOUNDATIONS COMPLETED, APRIL 11, 1914.

were mixed in the following proportions:—Cement mortar: 1 part cement, $\frac{1}{2}$ part sand, $1\frac{1}{2}$ parts grit. Cinder concrete: 1 part cement, 2 parts sand, 5 parts hard coal cinders.

Grit was delivered on scows at the dock used for receiving cement. Cinders were obtained from factories in the neighborhood. These materials were trucked to the building and stored on North Third Street. The cinder concrete base and cement top coat were mixed and hoisted in the same manner as the gravel concrete, the cinders and grit being wheeled to the mixers.

The hollow tile, for partition construction, was delivered on lighters, unloaded adjacent to the sand and gravel bins, and piled on the first floor near the platform hoist. (Fig. 4.) This hoist was placed in an elevator shaft. It consisted of a platform 5 ft. 6 in. x 5 ft. 6 in., operated by a single drum motor driven hoist. Tile was wheeled on the platform in wheelbarrows, and elevated to the various floors. The erection of tile partitions followed closely after the completion of the cement floors.

The platform hoist was also used for elevating all plaster

FIG. 8.—AUSTIN NICHOLS BUILDING, MAY 28, 1914.

and various materials entering into the work of the subcontractors.

The successful erection of this building was due to the efficient operation of the equipment herein described. All foundation work was finished April 11th and the roof was completed July 3d. (Figs. 7 and 8.) Between these dates 17,510 cu. yds. of concrete were placed in 62 working days, an average daily output of 282 cu. yds.

The derrick was capable of unloading 700 cu. yds. of material per day of 8 hours. The average capacity of each concrete plant was 45 cu. yds. of concrete per hour. The largest quantity of concrete placed in one day of $8\frac{1}{2}$ hours was 640 cu. yds.

The efficiency of the equipment for conveying materials from the bins to the mixers was demonstrated when, due to a slight breakdown, the derrick was idle for one day. In order to keep one mixing plant in operation, sand and gravel were wheeled from emergency storage piles on North Third Street. Charging one mixer in this way required 22 additional men, and reduced the output of the plant to about 30 cu. yds. per hour.

In order not to delay the progress of the work, it was necessary that the reinforcing steel be placed immediately after the completion of the forms. This required that work in the steel yard be so systematized that the bending and fabrication of steel would be sufficiently in advance of requirements to prevent any delay in the work.

Beam and girder bars were bent at an average rate of 125 per hour, while the capacity of the stirrup bender was 4,000 stirrups per day.

The total labor cost for installing all equipment used in the erection of the building amounted to $.20 per cu. yd. of concrete. It must be borne in mind, however, that this cost does not cover any charge for material or use of plant, depreciation or interest on equipment investment.

This building was erected for Havemeyers & Elder, and leased by them to Austin, Nichols & Co., Wholesale Grocers. The Turner Construction Co. executed the general contract under the direction of Mr. Cass Gilbert, Architect.

DISCUSSION.

Mr. W. A. Collings.—There are several mills, I understand, bending anything larger than $\frac{3}{4}$ in. bars at a cost of $4 a ton. I would like to compare that cost with your experience. Mr. Collings.

Mr. E. J. Moore.—While the bending of steel could probably be done at the mill fully as cheaply as in the field, it generally happens that the changes made during construction makes it impracticable. Mr. Moore.

Mr. Collings.—Would you not consider the bending at the mill and the ease of handling on the job as affecting it practically? Mr. Collings.

Mr. Moore.—Yes, if the bars are bent at the mill it facilitates handling. Mr. Moore.

MECHANICAL PLANT FOR HANDLING CONCRETE.

By W. P. Anderson.*

A mechanical plant for handling concrete varies with the character and extent of the work and the conditions at the site. In this article I am outlining some of the methods used in reinforced concrete buildings, and it should be borne in mind that in work of this class the opportunity for extensive labor-saving devices is not as great as in work where greater masses of concrete are handled.

There are two classes of equipment which can be used in a mechanical plant for handling concrete. One class is that which is standard and can be used on nearly every job. This class consists of mixers, hoists, charging and placing barrows and similar equipment. For this class of equipment the contractor need never hesitate to buy the best in the market as it can be used over and over again and is always a good asset. The second class covers that which can be used in special cases only, such as unloading devices, industrial track and cars, cableways and other special machinery. The contractor should be very careful before investing in the latter form of equipment, as in many cases, unless the character of work which he is doing is such that this special equipment can be used on succeeding jobs, its cost will more than make up for the saving in labor gained by its use. This is particularly the case with large elevated hoppers for holding the concrete aggregate, as the salvage from these hoppers at the end of the job is small compared to their total cost, and unless the job is a very large one the saving in labor does not equal the expense of installing the hoppers and the necessary extra equipment needed when they are used.

A common method of handling concrete on a building is as follows: The material comes to the building either by wagon or on cars. The cement is stored in a shed built for that purpose and the sand and stone are unloaded directly on the ground as near

* President of the Ferro Concrete Construction Co.

to the mixer as possible. If the building has a cellar below the level on which the material is stored, the mixer is placed in this cellar, and a charging hopper placed above the mixer with a platform around its top, on or slightly below the level of the ground where the material is stored. The aggregate will be taken from the storage pile by buggies to the charging hopper and after the concrete is mixed it will be hoisted and dumped into a distributing hopper, above the floor being concreted, from which point it will be taken by buggies or chutes to the place where it is to be used.

Of course conditions arise at times when certain modifications of this scheme can be used to advantage. There is a tendency sometimes, however, to put in too much equipment and the contractor will find that the saving in labor does not equal the cost of special equipment. The contractor also must take into consideration that in putting in elaborate equipment he is put to this expense at the start of the job, while the labor cost which it replaces is distributed over the entire length of the job and, therefore, it requires more money to carry on a job with such equipment.

Where material is delivered at the site of a building by rail and the mixing plant can be located conveniently near the switch; often it will be found a great advantage on a job to handle the aggregate directly from the cars to the mixers without storage. Where this is done it is well to store some of the aggregate for emergencies. A convenient arrangement of the plant for this purpose is bins built along the unloading switch. These bins need consist of one partition only, about 2 ft. away from the edge of the car, with the top of the partition brought up to the height of the floor of a freight car; a division partition in the opposite direction run out about 10 ft. to separate the fine and the coarse aggregate; a platform about 6 ft. wide built at the top of the bin, the planks on it not being nailed so that when it is desired to unload directly into the bins this can be done by moving the planks over to the edge of the platform, which should run, preferably with a downward grade, to the mixing plant. Of course, when this arrangement is followed demurrage on cars is nearly always unavoidable, as it is difficult to arrange to have them come in at the exact time they are wanted, but it saves rehandling of material, and in a number of cases this saving is greater than the extra charge incurred for demurrage. On a very large

job it may pay to build two overhead charging hoppers, one for sand and one for stone, and have these so located that the material can be dumped by gravity directly into the mixing hopper. The mixing hopper can be constructed so that it will have sufficient sand for a charge when it is filled to a certain height. Then the stone can be added to another height, and after the cement is added the charge will be ready for the mixer, into which it will be dumped by gravity. Where this arrangement is used a derrick may be placed in such a manner that material can be unloaded directly from cars to the storage hoppers by clam shell or similar equipment, which can also be used for unloading onto a storage pile on the ground, as it would be inadvisable to build the storage hoppers sufficiently large to provide for all the material which would be required. As a general thing, however, it would be possible to locate the unloading derrick in such a position that material can be taken directly from the cars to the storage hopper, from the cars to the storage pile, or from the storage pile to the storage hopper. In either of the above plans the object is to handle as much material as possible directly from cars to storage hopper or mixer without a double handling.

In unloading material from cars where the above arrangement is not practicable, sometimes it is found advantageous to have a hopper which can be fastened to the side of a car; and material can be shoveled from the car directly into this hopper. The advantage of this is that no time is lost in shoveling from the car, and also that more trips can be made in hauling material from the car, as there is no long wait during loading.

In our work we have found that where a level run can be used, a two-wheel buggy holding 4 cu. ft. is the most convenient form of equipment for getting the aggregate from the storage piles to the mixing plant. Where wheeling is bad an end-dumping 3-cubic-foot wheelbarrow can be used to better advantage. These barrows are used as a gage for measuring material. In some cases, however, where material comes in by rail and the switch is over 200 ft. from the mixing plant, it will be found advantageous to transport the aggregate from the switch to the mixer by industrial tracks and small side-dumping cars. Where conditions are such that the mixer cannot be placed low enough to have the cars dumped directly into the hopper above the mixer, without

elevation, cars can be brought up an incline to the desired point and dumped directly into the charging hopper, and where this is done, the cars can be hauled up this track by the same engine which operates the mixer and the rest of the track can be graded so the cars operate by gravity.

On one job in the writer's experience where double tracks were to run into the building after it was completed, it was found practical to place the mixer at the end of these tracks, and as soon as the concrete had been finished to the point where the tracks were to go, the latter were put in place and cars were backed up within 10 ft. of the mixer. A small 6-in. I-beam track was placed above the center line of each car and this track ran to a point above the charging hopper which emptied directly into the mixer. A scraper similar to an ordinary dirt scraper was used for conveying the material from the car to the charging hopper. A steel cable was attached to this scraper and passed over an 8-in. sheave, attached to an overhead traveler which ran on the I-beam track. The cable ran along the line of the track, and was attached to an extra drum on the hoisting engine. The traveler was about 18 in. long and extended about 4 ft. below the track and on this lower portion was a catch to hold the scraper when the traveler was in motion. A lever released this catch, allowing the scraper to drop and at the same time lock the traveler to prevent it from sliding back towards the mixer. The locking device was not sufficient to prevent this sliding entirely and a rope was used to hold the traveler in position while loading the scraper. The I-beam tracks were long enough to unload two cars on each track without switching, and as we were able to have cars switched morning and noon, we could unload eight cars of aggregate a day. On this job there was practically no room for storage of aggregate and it was handled directly from car to mixer. The I-beam tracks were inclined so that the empty scrapers returned to the car by gravity.

The location of the mixing plant on any job is determined by two factors: first, depending on the ease of getting the materials of which the concrete is composed delivered near the plant; second, the position of the plant relative to distributing the concrete to all parts of the work with as little labor as possible. A mechanical mixer is essential on all jobs of any magnitude. A batch mixer is most commonly used for reinforced concrete work

and we find what is known as a 4-bag mixer the most convenient size for general work.

Often it is necessary to place some of the concrete footings before the mixing plant can be located permanently for the building construction and in a number of cases it will be found as cheap to do this preliminary concrete work by hand as in any other manner. Therefore, when the mixer is finally set up, it is generally in a permanent position for mixing the concrete for the job in question.

In nearly all cases it will pay to arrange the mixing plant so that the cement and aggregate can be dumped into a charging hopper which allows a complete charge to be dumped into the mixer at one time. This saves time, as while the mixer is mixing one charge, another charge can be prepared. In laying out this plant it is best to have this charging hopper stationary and above the mixer so that the charge can go directly into the mixer without being elevated, and often it will be found cheaper in the end to dig a hole in which to place a mixer, than to use any elevating machinery. However, in some cases where the work is not extensive enough to warrant this expense, some form of hopper can be used into which the material can be dumped, lifted and dumped into the mixer. Mixers are sold with attachments of this kind which can be used when desired or can be removed and the mixer used without the attachment.

Another very satisfactory arrangement of plant, where the mixer cannot be charged by gravity without elevating the aggregate, is to have a bucket hoist adjacent and similar to the concrete hoist. The charge is dumped dry into this bucket, elevated and dumped into a stationary charging hopper, and from there goes by gravity to the mixer. This method has the advantage of having two charges ready ahead of the mixer. The same engineer and engine that is used on the regular hoist can be used here.

The hoist which we have adopted for our work on ordinary buildings is a bucket hoist with a frame tower, with lumber cut to standard sizes so they can be used on any job. The concrete dumps directly from the mixer into the bucket and is lifted and dumped into the distributing hopper. This hopper is raised to the desired height on the tower by a block and fall. We usually take concrete from this hopper either by two-wheel buggies containing about 6 cu. ft. or by concrete chutes. It is necessary to have

runways for these buggies which are formed by 2 x 12 in. planks raised on small trestles about 1 ft. high which keeps the runway above the steel reinforcement. The hopper is kept at sufficient height so that the buggies can get underneath the chute at its lower end.

Where the building covers a good deal of ground often it is found convenient to chute the concrete from the main hoist to various portions of the work and in some cases to re-elevate and re-chute. The angle of the chutes depends somewhat on the character of the concrete and of the aggregate of which it is composed. We have found a convenient slope is 1 ft. vertical to 4 ft. horizontal. Where wire ropes are used to suspend the cable, the ropes should be drawn as taut as possible so that the inclination of the slope of the chutes will not vary when concrete starts to flow through them. A convenient way of drawing this rope taut is to stretch the rope as tight as convenient and then attach another rope to it and pull down on this. Another convenient method of handling chutes is to have a boom attached to the concrete hoist. We have found that a convenient arrangement for this is to have chutes about 34 ft. long, one end of the chute being attached to the bottom of the hopper at the top of the hoist, with gate to allow concrete to run into the chute as desired. The other end of the chute is held by a line attached to the boom above that end of the chute, the boom being a split-boom so designed as to allow the chute to pass through the boom. Another chute of this same length can be attached to the lower end of the first chute and concrete from the first dumped into the second, the lower end of the second chute held above the floor on which concrete work is being done by a light A-frame made of wood. The boom should extend 10 or 12 ft. beyond the point where the first chute is attached and a block and fall run from the end of the boom to a point on the second chute 5 or 6 ft. from its lower end. Then when it is desired to move the second chute this end can be raised by the block and fall and swung to a new position. It will be found that this will hardly answer for the purpose of holding the chute when concreting so that the A-frame under the lower end will be necessary and the block and fall is used only for the purpose of changing the position of the chute. A small chute 10 or 12 ft. long which is moved by hand can distribute the concrete from the

end of the second. Of course, in chuting this way the distance the concrete can be taken is limited, but we have found this a very satisfactory method where the distances are not too great. Very often it is found advisable to chute the concrete to certain points on a job and wheel from these points to the position where it is used.

Another method of handling concrete on buildings is the use of large derricks and bottom-dumping buckets. We tried this method on several jobs, using two 80-ft. boom derricks, which were placed on wooden towers adjacent to the buildings, the towers being high enough to allow the boom to clear the roof, so that the derricks were not moved after once placed until the job was completed. The buckets were large enough to receive one charge direct from the mixer, and the concrete was dumped, in most cases, directly on the forms where used, but in some cases, where the derrick would not reach, the concrete was dumped into a hopper and from there wheeled to place. These booms could be used also for hoisting form work, steel and other building material. The disadvantage of this plant is that its use is limited because it requires room for placing and operating the derrick, which is not always available, and also in congested districts often it is impossible to guy the derrick. The cost of placing and removing the derrick is so great that it can be used economically only on large jobs. Therefore, as the first cost of this form of equipment is rather great and its use restricted, it is not recommended for general use.

CONCRETE FORMS FOR THE CATSKILL AQUEDUCT.

By Alfred D. Flinn.*

In the Catskill aqueduct, the dams and the numerous other structures built by the Board of Water Supply of the City of New York to date, 4,500,000 cu. yds. of concrete have been placed, using 6,500,000 bbls. of Portland cement of 18 different brands. For the 55 miles of cut-and-cover aqueduct, and 50 miles of concrete-lined tunnels, steel forms have been used almost exclusively; for the 6 miles of mortar-lined and concrete-jacketed 9-ft. and 11-ft. steel pipes, wooden forms were preferred. Concrete blocks for the facing and expansion joints of Olive Bridge masonry dam were pre-cast in wooden forms containing steel plates for giving a smooth finish to that face of each block which would be exposed when placed on the dam. Similarly, blocks for Kensico dam were cast in steel forms. For gate-chambers, corewalls of earth dikes, concrete waste weirs; for the eleven girder and arch reinforced bridges; for aqueduct junctions, curves, transitions and bell mouths, and for other special structures and parts of structures, the forms were almost wholly of wood. Metal was, however, used for structural members of some large wooden arch centers and of some wooden forms, and for special features requiring great accuracy and smoothness. Pictures and drawings illustrating this paper show many of these forms and indicate methods of use. Incidentally, various types of aqueduct and other structures are shown also. In Fig. 1 are several typical aqueduct cross-sections.

So many articles describing the Catskill water works have been printed in the technical press since active construction began in 1907, that members of the Concrete Institute are assumed to be sufficiently well informed to read understandingly the following descriptions and discussions of the concrete forms used for the aqueduct, under the headings: Forms for Cut-and-Cover Aqueduct, Forms for Lining and Jacketing Steel Pipes, Forms for Grade and Pressure Tunnels, Shaft Forms, Forms for Con-

* Deputy Chief Engineer, Board of Water Supply, City of New York.

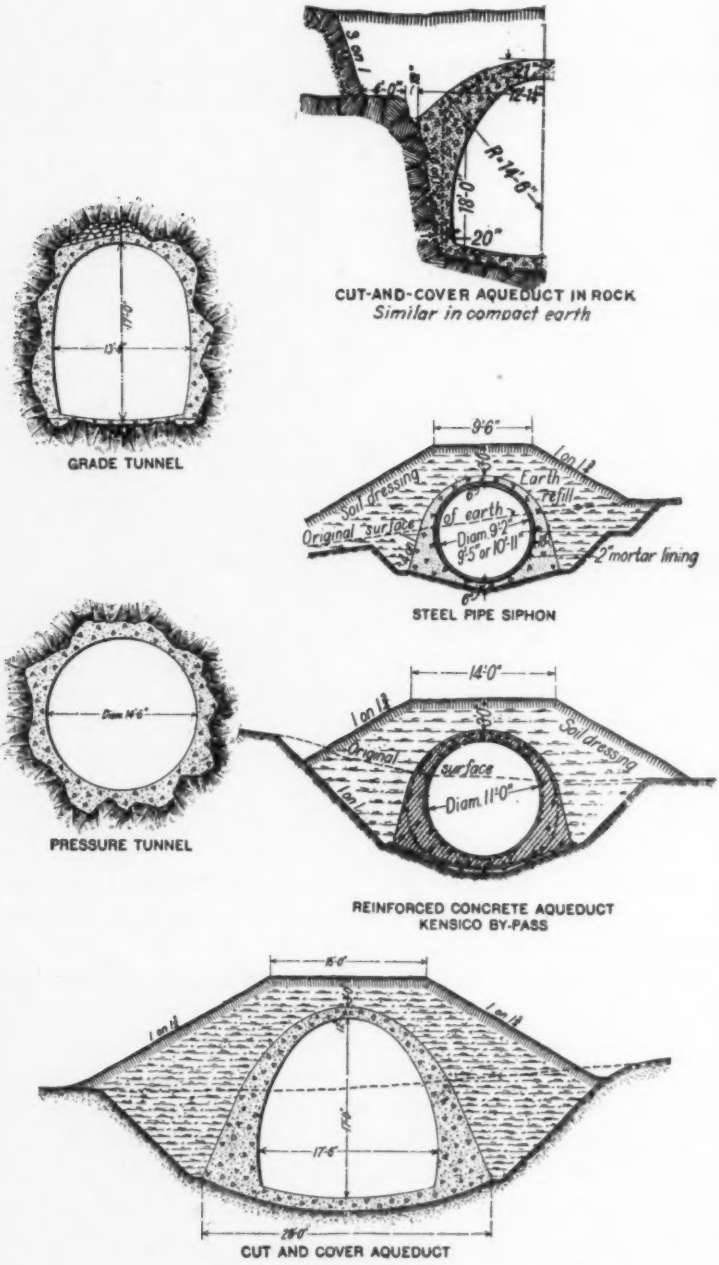


FIG. 1.—TYPES OF CUT-AND-COVER AND TUNNEL.

crete Blocks, Forms for Gate-Chambers and other Special Structures, Forms for Bridges and Fence Post Molds. A few notes on cost, methods and progress will be given incidentally. A book would be necessary for the full treatment of this subject; this paper can be only a partial statement.

FORMS FOR CUT-AND-COVER AQUEDUCT.

In standard cut-and-cover aqueduct, of the form shown in the illustrations, 17 ft. high and 17½ ft. wide inside, commonly concrete in the invert, or bottom, was placed first, in alternate

FIG. 2.—WOODEN FORMS FOR FIRST 3000 FT. OF CUT-AND-COVER AQUEDUCT, WHICH WAS BUILT IN THREE PARTS, INVERT, SIDEWALLS AND ARCH. CONCRETE KEY BLOCKS AT JOINTS IN INVERT WERE BUILT IN ADVANCE.

blocks 15 ft. long, and, after the hardening of the invert, the remainder, called the arch, was cast in one operation. In three localities, however, the contractors divided the structure into invert, sidewalls (about 8 ft. high), and arch.

End forms for the invert blocks were usually steel plates, but sometimes were made of planks cut to the curve of the intended surface. Side forms were straight planks. Surface finish was obtained by sliding on the side forms a plank screed with a steel edge cut to the invert curve, or by sliding a straight screed on the end forms, or by rolling with a piece of steel shafting, or a

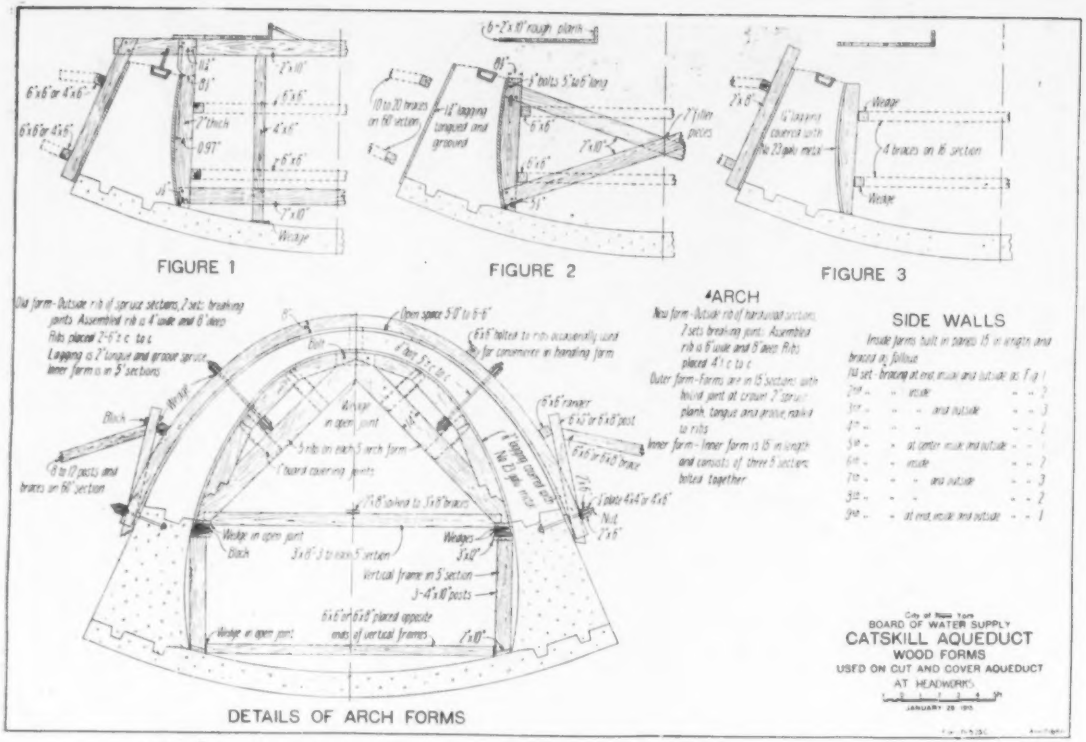
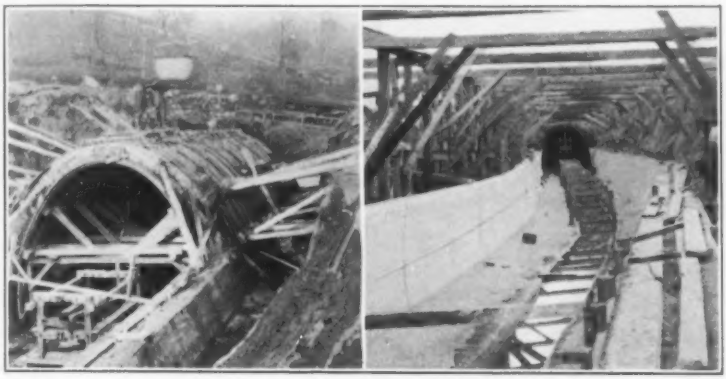


FIG. 3.—WOOD FORMS USED IN CONSTRUCTION OF CUT-AND-COVER AQUEDUCT.

concrete-filled steel pipe about 4 in. in diameter, traveling on the end forms.

Joints in the arch and sidewalls were required to coincide with invert joints within reasonable limits; therefore, sidewalls and arch were constructed in lengths which were some multiple of 15 ft.,—usually 30, 45 or 60 ft. They were not permitted to exceed 75 ft. on account of the likelihood of intermediate cracks in greater lengths.

When determining the alinement of the aqueduct it was



FIGS. 4 AND 4*a*.—WOODEN FORMS FOR WALLKILL CUT-AND-COVER AQUEDUCT; ARCH FORMS CONSISTED OF 3-IN. STEEL ANGLE RIBS COVERED BY 2-IN. WOODEN LAGGING AND WERE BRACED WITH WOODEN STRUTS DURING CONCRETING. IN FIG. 4 THE TROUGH CONVEYED WATER ENCOUNTERED IN THE TRENCH.

believed that curves having radii of 700 ft. or more could be built with the forms used for tangents. Wherever sharper curves were needed, they were made uniformly of 200-ft. radius. It was found impracticable, however, to build the flatter curves satisfactorily without some special device, such as wooden fillers at the joints between the form sections on the outer side of the curve. Special forms for curves are inconvenient since they need to be placed in and removed from the trench at each curve. One of the form builders ingeniously overcame this difficulty by making all forms in 5-ft. lengths, beveled, so that when placed with long and short sides alternating the assembled form was

suitable for straight aqueduct, and when assembled with the long sides contiguous, curves of 200 ft. radius were formed by means of 5-ft. chords.

Sidewall construction as a separate step was pursued successfully only on the 3000 ft. of aqueduct built with wooden forms adjacent to the headworks at the Ashokan reservoir, as a part

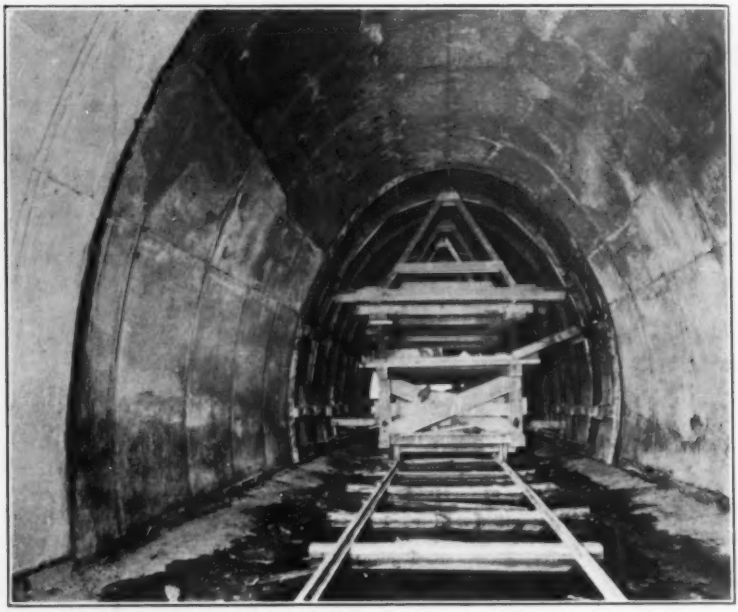


FIG. 5.—MCNALLY COLLAPSIBLE CUT-AND-COVER AQUEDUCT FORMS. DURING CONCRETING THEY WERE BRACED FROM THE CARRIAGE USED FOR THEIR TRANSPORTATION. OBSERVE CHARACTER OF INTERIOR SURFACE OF AQUEDUCT; IT WAS MUCH BETTER IN LATER WORK.

of the headworks contract. On a short stretch in the Wallkill valley sidewalls were built separately, but this method was abandoned before the end of the first season. Elsewhere the desire to build sidewalls separately grew out of an apprehension of difficulty in holding outside forms in place for the "compact earth" type of aqueduct, and only a very short piece was so built. Experience quickly proved this apprehension to be groundless. Genuine difficulties were, however, developed by the

attempt: the narrow space between inside and outside forms at the top of the sidewall necessitated exact placing and careful emptying of the large concrete buckets, which made the filling of the forms slow and troublesome; it was more difficult to hold these forms in place.

One endeavor was made to dispense with a wooden sill for supporting sidewall or arch forms by building about 6 in. in height of sidewall with the invert. This was unsuccessful on account of the difficulty in producing a satisfactory surface on top of these low walls.

FIG. 6.—OWEGO INSIDE CUT-AND-COVER AQUEDUCT FORMS ABOUT TO BE PLACED IN POSITION. THE H-BRACES ARE SHOWN TO THE LEFT. THE METHOD OF SUPPORTING RAILS FOR TRANSPORTATION OF FORMS IS CLEARLY SHOWN.

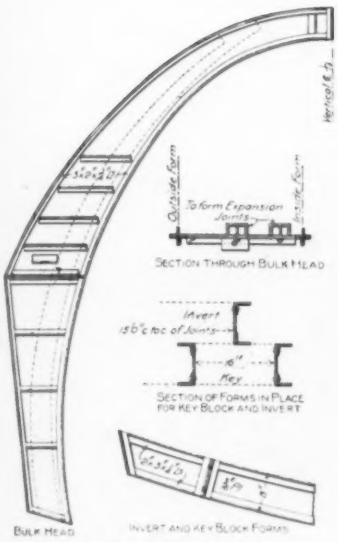
Wooden Forms for Cut-and-Cover Aqueduct.—Wooden forms used successfully for the portion of the cut-and-cover aqueduct at the headworks are shown in detail by Fig. 2. Sidewall forms were in 15-ft. sections and handled by a derrick; special panels shaped to the arc were used at curves. Diagonal bracing was expected to be adequate, but it was soon found necessary to add the longitudinal and transverse 6 x 6-in. pieces. For the second construction season 15-ft. planks were spiked to the tops and bottoms of the posts of the inside forms and some of the diagonals discarded.

Arch forms were built in 5-ft. sections, three being bolted together for convenience, except on curves, where extra ribs were inserted between sections on the outer side of the curve. These forms were supported on frames resting on the invert, as shown in Fig. 3. To collapse the forms, turnbuckle rods were used, having a U iron on each end engaging a rib by means of a bolt through the rib and U iron. In moving arch forms ahead,

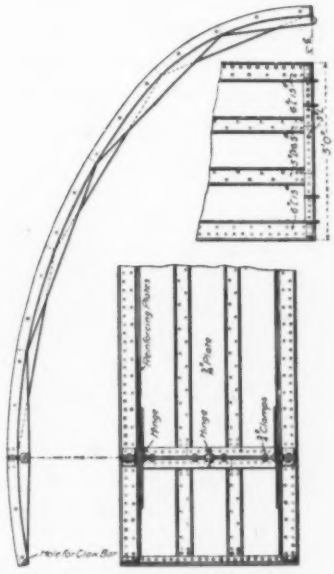
FIG. 7.—EARLY TYPE OF BLAW COLLAPSING AND TELESCOPING CUT-AND-COVER AQUEDUCT FORMS. THIS FORM CONTAINED THREE HINGES, ONE AT THE TOP AND TWO AT THE SIDES NEAR THE BOTTOM. THE BOTTOM OF THE FORM WAS BRACED ACROSS THE INVERT WITH WOODEN STRUTS BEARING ON THE TRACK STRINGERS.

2-in. pipe rollers were used, traveling on the frames. Across the forward end of the sidewalls a timber was placed, carrying a pulley block; one end of the rope through this block was attached to the arch form to be moved and the other led to a hoisting engine.

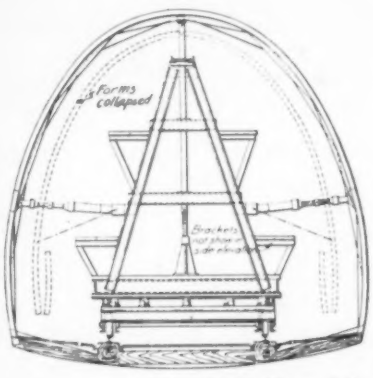
Sidewall forms were set $\frac{1}{2}$ in. wider, and arch forms $\frac{1}{4}$ in. higher than the theoretical dimensions of the aqueduct. Frequent driving of the wedges between the arch forms and the sup-

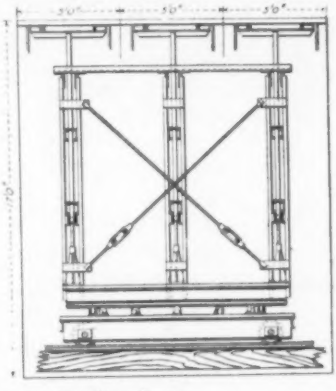


Steel Forms for Bulkhead and Invert.



Collapsible Forms for Inside of Aqueduct.





End and Side Views of Carriage for Handling Forms.

FIG. 8.—EARLY TYPE OF BLAW CUT-AND-COVER AQUEDUCT STEEL FORMS.

porting frames was necessary during concreting. Outside forms were removed after 12 to 24 hours, inner sidewall forms after 48 hours, and arch forms after 72 hours. Results were quite satisfactory. Near the conclusion of the work, however, these wooden forms began to distort and probably could not have been used much longer. Although lower in first cost than steel forms they would probably not be so economical in building a long piece of aqueduct.

FIG. 9.—BLAW INSIDE CUT-AND-COVER AQUEDUCT FORMS IN POSITION ON A CURVE.

Another type of wooden forms was used on the stretch of Wallkill cut-and-cover aqueduct in which sidewalls 8 ft. high were built separately, but these forms were not satisfactory either to the engineers or to the contractor. Inside forms were built in panels 15 ft. long, with 2-in. lagging, covered with sheet iron, on ribs 4 ft. apart. Sidewall forms rested directly on the invert concrete, no sills being used, and were held apart by trench braces between the wooden ribs of the forms. The ribs had suitable attachments, top and bottom, for receiving these braces, which were also used for collapsing the forms. Arch forms had steel

T ribs, 4 ft. apart, to which 3-in. wooden lagging was fastened by screws, which were braced by radial wooden struts, and were supported on a carriage resting on wooden horses standing on the invert. In these arch forms metal cross braces at the bottom, equipped with turnbuckles, provided means of bracing and collapsing the forms. On curves the forms were sprung approximately to the required curvature. Steel T ribs and ship-lap lagging were used for outside forms. Sidewall forms were moved by a derrick and the outside forms piecemeal by hand. These forms prevented rapid progress and were superseded by steel forms on that account, although the results were satisfactory. They were not used long enough to test their durability. A great deal of bracing in addition to that required by the original design was required. Figs. 4 and 4*a* show these forms.

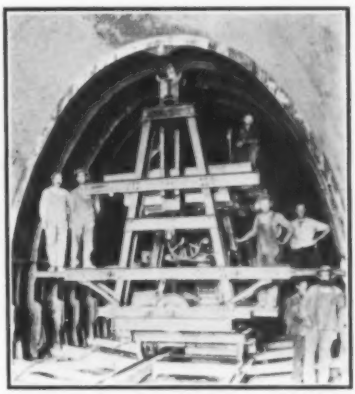


FIG. 10.—LATER TYPE OF BLAW COLLAPSING AND TELESCOPING INSIDE CUT-AND-COVER AQUEDUCT FORM.

Steel Forms for Cut-and-Cover Aqueduct.—Lacking precedent for structures of such magnitude as the Catskill aqueduct, designs for steel forms could be perfected only by trial and correction. Consequently, it was not surprising that the forms produced during the first season of active concrete work (1909) should have been full of faults, nor that experience should have led to a standard type which was subsequently used on most of the work, with minor modifications to suit special cases or individual preferences. Most of the serious faults were corrected in the forms used the second season. As knowledge of what has been tried without success is often valuable, brief statements will be given about some of the early forms and their failings before describing the forms which emerged finally. In general, workmanship was poor, often bad; materials were too light; and the parts were not so disposed and connected as to develop their strength to the best advantage. Joints between sections of forms were not made with sufficient accuracy and the countersunk rivet heads

in the outer surface of the inside forms were not sufficiently smooth. In some cases, adjoining sections of forms could be brought together only with great difficulty. Since the problems relating to inside and outside forms were distinct, they will be dealt with separately.

Inside Forms for Cut-and-Cover Aqueduct.—Lightness, ease of moving, and collapsibility so as to be telescoped through forms in position, were desired by many contractors. Four makes of

FIG. 11.—RANSOME COLLAPSING AND TELESCOPING INSIDE CUT-AND-COVER AQUEDUCT FORM. THIS FORM CONTAINED THREE HINGES, ONE AT THE TOP AND TWO AT THE SIDES NEAR THE BOTTOM. THE BOTTOM OF THE FORM WAS BRACED ACROSS THE INVERT WITH WOODEN STRUTS BEARING ON THE TRACK STRINGERS. OUTSIDE FORMS AND BULKHEAD ARE SHOWN, ALSO THE CARRIAGE.

steel inside forms were used in the early aqueduct building,—the McNally, Owego, Ransome and Blaw.

McNally forms, Fig. 5, were non-telescopic, collapsible only to pass through the finished aqueduct, and were used in three 50-ft. lengths, concreting being done at three locations on successive days. The bulkhead being set 5 ft. inside the end of the form, 45 ft. of arch were cast each time. These forms were without a hinge at the crown, but had a bolted joint at each side, 7 ft. 9 in. above the bottom. To collapse the forms, the wooden

sills were first "kicked" out, then the bolts in the side joints were loosened, leaving the lower plates suspended, and finally the whole form was dropped on to a traveling carriage by means of screw jacks, 50 ft. of forms being moved and reset at one time. Numerous wood braces bearing on the carriage were used to stiffen the forms when set. Each form was made up of sections 5 ft. in length along the aqueduct. Surface plates were $\frac{1}{4}$ in. thick and were stiffened by 3 x 3 x $\frac{1}{4}$-in. longitudinal angles, 3 ft. from center to center; 4 x 4 x $\frac{5}{16}$-in. angles at the longitudinal joints; and 4 x 3 x $\frac{5}{16}$-in. angles at each edge of the 5-ft. sections, which constituted the ribs of the forms. For curves special forms were used. Under the bottom of the form on each side of the aqueduct a wooden sill was placed. Except the $\frac{1}{4}$-in. plates, this design

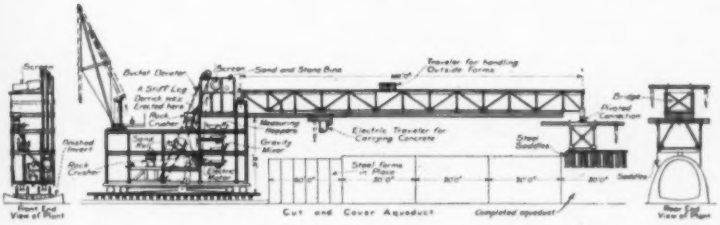


FIG. 12.—CONCRETING PLANT FOR THE ESOPUS CUT-AND-COVER SECTION OF THE CATSKILL AQUEDUCT, SHOWING SIDE, FRONT AND REAR VIEWS.

was weak. The longitudinal angles below the side joints should have been heavier. Transverse angles, or ribs, were too far apart and too light. The bracing from the carriage was inadequate.

Owego forms, Fig. 6, were collapsible and telescopic with a crown hinge and bolted joints in each side 8 ft. above the bottoms These side joints were made by bolting the horizontal angle. together and bolting splice plates to the webs of the channels used as ribs. It was intended to use these forms to build sidewall and arch separately, but they were so designed that they could be used also to build monolithically the portion of the aqueduct above the invert. Owego forms were built in sections 5 ft. long, of $\frac{1}{4}$-in. plate, with four 5-in. channel ribs placed transversely in each 5-ft. section. At the hinge, angles were riveted to the channels and one long bolt used as a hinge pin for the 5-ft. section. Horizontal cross-braces of 2-in. wrought-iron pipe were used at

the level of the side joints at intervals of 5 ft. in some places, but even with these braces, the sides of the forms moved inward appreciably. Later the pipe braces were discarded for others of steel H-beams. For curves, wood fillers were used between the 5-ft. steel sections. Workmanship was good. On the whole, good results were obtained with these forms in monolithic construction.

Ransome forms were made in 5-ft. sections with a crown hinge, and a hinge in each side 3 ft. above the bottom, each hinge having a continuous pin bolt. A wood sill was attached to the

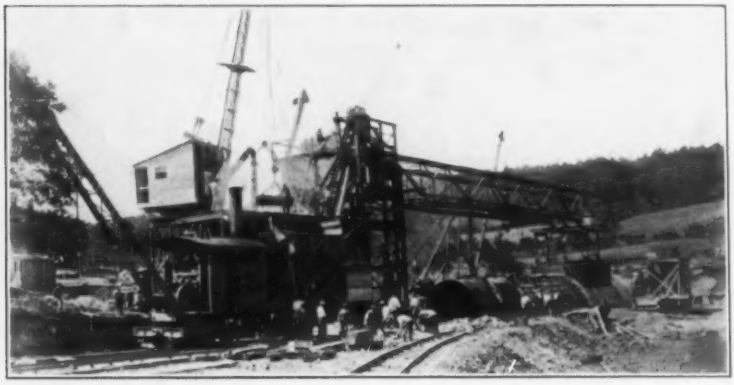


FIG. 13.—TRAVELING CONCRETE MIXING AND PLACING PLANT USED ON ONE SECTION FOR THE CONSTRUCTION OF CUT-AND-COVER AQUEDUCT. THE REAR END OF THIS EQUIPMENT WAS SUPPORTED ON THE COMPLETED PORTION OF THE AQUEDUCT.

bottom of the form on each side. Double carriages, each supporting 30 ft. of form, were used for moving ahead. Each carriage had a device for shifting the forms laterally by means of screw jacks, which also permitted the tracks to be laid somewhat off the center line of the aqueduct, the purpose being to avoid an obstacle or overcome inaccuracies in track alinement; this device was not worth the cost, for it was simpler to remove the obstacle or correct the track alinement. To collapse the forms the bottom leaf on each side was drawn up and then the top dropped by a system of levers actuated by cables on drums on the carriage, hand power being used, and four men dropping a

15-ft. section. The plates on these forms were $\frac{3}{16}$ in. thick. There were four transverse ribs in each 5-ft. section, two 4-in. I-beams and two 4-in. channels. No cross bracing was used. Workmanship was good. Wooden fillers were used at curves.

A modified Ransome form was given a trial in one portion

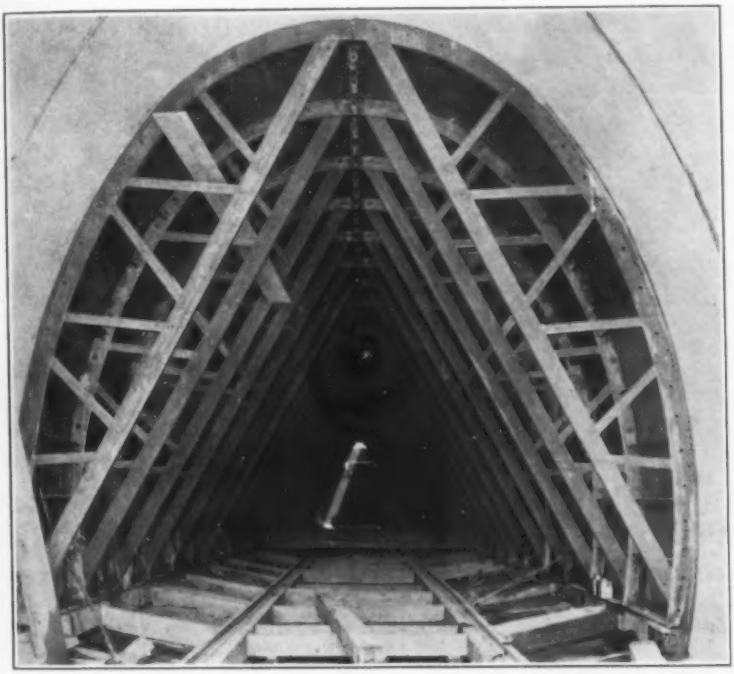


FIG. 14.—KING, RICE AND GANEY STEEL CUT-AND-COVER AQUEDUCT FORM. THIS FORM WAS RIGIDLY TRUSSED. IT HAD AN ARCH HINGE. PIPES WERE USED TO BRACE THE BOTTOM OF THE FORM. BY REMOVING THESE PIPE BRACES, THE FORMS WERE COLLAPSED. FORMS WERE NON-TELESCOPING. TRUSS MEMBERS AND THE RIBS ARE STEEL ANGLES.

of the aqueduct. Inside each joint between 5-ft. sections of form, there was an $\frac{1}{8}$-in. steel skiding plate attached with bolts through slotted holes, so that these joints might be opened on one side at curves. Blue clay or a similar substance was used to fill the depression thus formed and prevent a projection on the concrete surface. This sliding plate interfered with the use of a heavy

rib close to the end of the section as was needed for stiffness. In this type of form there were three 4-in. I-beam ribs, $20\frac{1}{2}$-in. from center to center. The sliding plates gave trouble when removing the forms and the forms became distorted so as to occasion costly delays and work in re-erecting them.

Blaw forms, Figs. 7 and 8, were collapsible and telescopic, with a crown hinge and a hinge in each side 3 ft. above the bottom. They were designed for monolithic construction above the invert and made in 5-ft. sections. Each section was beveled so that by reversing a suitable number, a curve of standard radius could be made. For this purpose each form carriage was built with a turn table. Wood sills were placed and braced on the aqueduct invert before the forms were set up. Early forms of this type were much too light and had many faults of design and workmanship. Experience led to correction of these errors and ultimately a much greater length of aqueduct was built with Blaw forms than any other. Plates on the first forms were only $\frac{9}{64}$-in. or $\frac{1}{6}\frac{2}{4}$-in. thick. For ribs each 5-ft. section had two 5-in. standard steel channels and two 6-in. ship channels with webs against the plates, and two built-up members made of plates bolted to the inside flange of each ship channel, the latter being at the ends of the section. Adjacent sections were fastened together by bolts through an angle on each edge of the section. These built-up members contained the hinges, which had punched holes. The hinge pins were short bolts at each joint. Special carriages long enough to support three sections were provided for moving the forms, having three screw jacks for each 5-ft. section. The gage of the track for the carriages was $7\frac{1}{2}$ ft. In moving the forms, the 3-ft. leaf on each side was first drawn up and secured to the upper portion of the form, and then, by means of the screw jacks, beginning at the bottom, the sides of the forms were peeled

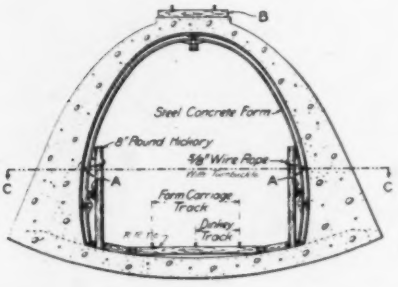


FIG. 15.—WOODEN POST AND WIRE ROPE TRUSSING FOR SIDEWALL FORMS OF CUT-AND-COVER AQUEDUCT.

from the concrete and they were lowered so as to pass through forms in position. These early Blaw forms were not stiff enough.

Imperfections Resulting from Unsatisfactory Inside Forms.—Several distinct kinds of imperfections in the concrete resulted from the unsatisfactory forms. Roughly fabricated forms left impressions of rivet heads and joints, and caused offsets where successive days' work joined, sometimes as great as 2 in. Insufficiently rigid forms yielded under the concrete pressure so as to make a wavy surface. Occasionally leaks caused stony concrete with little mortar. These troubles were soon overcome and

FIG. 16.—EXTERIOR FORMS FOR CUT-AND-COVER AQUEDUCT USED IN CONJUNCTION WITH THE MCNALLY INSIDE FORMS. THEY CONSISTED OF ANGLE RIBS AND WOODEN LAGGING, AND WERE BRACED BY SUSPENDERS AT THE TOP. BULKHEAD IS SHOWN ALSO.

such imperfections as had resulted were in the main corrected. A liquid concrete was used for practically all the aqueduct work. Where one man, for each 15 ft. of length, spaded the concrete in the form on each side of the aqueduct, the best results were obtained.

Sandy surfaces were common, especially on the sidewalls between 1 and 6 ft. above the junction with the invert, and were traced to leaking of the forms and to washing by water from freshly placed concrete above, the forms having separated slightly from the lower, partially set concrete due to the increasing pressure. Calking of joints, especially the side hinge joints,

and stiffening of forms by bracing or other means cured this trouble. Another result of leaks was the inflow of grout on to the invert, which was difficult to remove after it had set. To reduce the difficulty of removing this grout, sand was sprinkled over the invert in some places. However, this trouble was only temporary and probably due, in large measure, to a defective sill.

When removing the forms, a thin skin of concrete often came

FIG. 17.—STEEL OUTSIDE FORMS BRACED WITH RAILROAD IRON. USED IN THE CROTON DIVISION. BULKHEAD AND INSIDE FORMS ARE ALSO SHOWN.

away, leaving a rough surface, but in the aggregate only a small portion of the aqueduct was so affected. This defect, frequently called "peeling," was most pronounced with forms that were dropped. When by use of the crown hinge, the forms were separated gradually from the concrete, beginning at the bottom of the sidewalls, before being lowered at the top, the trouble was largely overcome. Naturally the condition of the surface of the forms

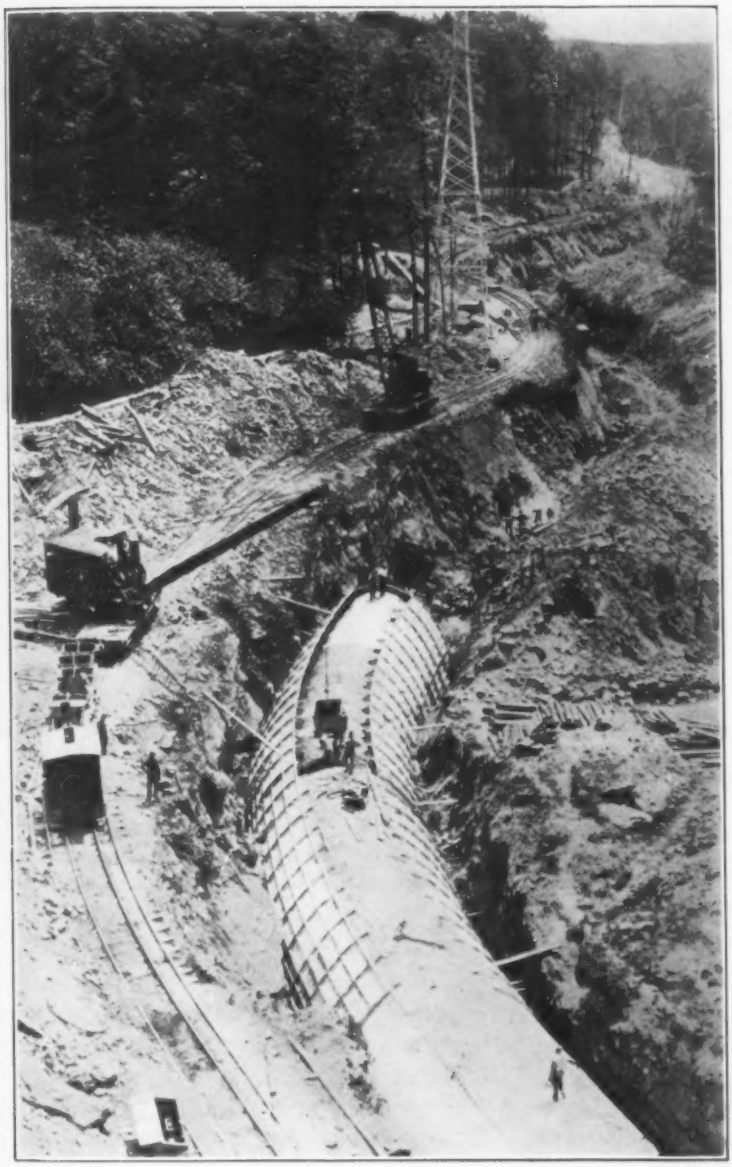


FIG. 18.—BLAW OUTSIDE CUT-AND-COVER AQUEDUCT FORM ALONG THE CURVE. METHOD OF DEPOSITING CONCRETE IS SHOWN, ALSO CURVED ALIGNMENT OF AQUEDUCT ON DIFFICULT TOPOGRAPHY.

and the lubricant to be used received consideration in this connection.

Numerous lubricants were tried, including crude petroleum, "Blaw oil," "Form oil," crude vaseline under various trade names, such as Petrolatum and Petroline; cylinder oil, cup grease and black oil, Albany grease, red oxide and other paints; combinations of oils and vaselines, mixtures of kerosene oil with crude oil and vaseline, oil over whitewash, and "Special Coating for Concrete Forms." Of these, one of the most successful was

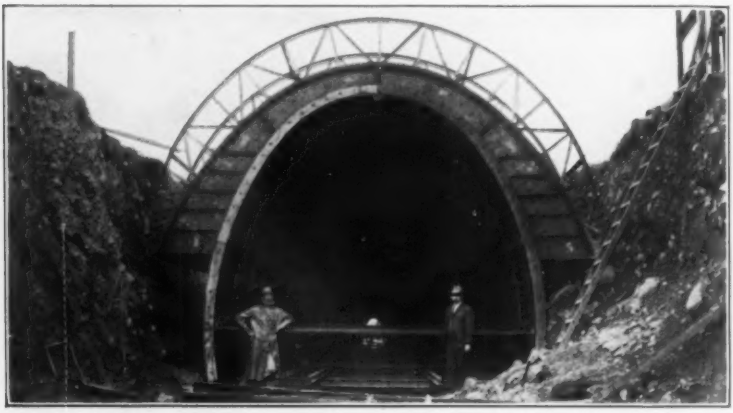


FIG. 19.—OWEGO FORMS FOR CUT-AND-COVER AQUEDUCT CONSTRUCTION. THIS FORM WAS COLLAPSIBLE AND TELESCOPING. IT HAD AN ARCH HINGE AND TWO SIDEWALL HINGES. THE LOWER PORTION OF THE FORM WAS BRACED WITH STEEL H-BEAMS. THE OUTSIDE FORMS WERE SUPPORTED BY THE TRUSSES. BULKHEAD IS SHOWN. THIS IS AN EXAMPLE OF "COMPACT EARTH" TRENCH.

a mixture of crude petroleum and crude vaseline in such proportions as to give a heavy oil. This was applied with a whitewash brush after the steel had been thoroughly cleaned. Crude oil should be thickened with some kind of crude vaseline during the warmer weather and should not be thinned with kerosene. In general, satisfactory surfaces of concrete did not result where kerosene was used as a component of the lubricant. On one stretch of aqueduct "Form oil" gave good results at the beginning of the season, but during the hot weather much peeling

took place, which was eliminated when a mixture of cup grease and black oil was substituted. One contractor eliminated peeling at the top of the aqueduct by lubricating the top of the form with asphaltum and protecting the lubricant by steel plates on which the concrete was dumped. At another place a little dry cement was sprinkled on the top of the form. At still another place, the lubricant on top of the form was protected by spreading one or two batches of mortar over it.

To prevent removal of the lubricant and scratching and pitting of the steel plates at the tops of the inside forms by dumping of concrete, a protecting steel plate was used in some places to receive the concrete. At other places the top surface of the form was carefully cleaned and re-oiled just before completing the arch. This latter operation also proved helpful in preventing the adhesion to the forms which resulted in removing the skin of the concrete, but no lubricant was found which would absolutely prevent the removal of the concrete skin where the forms were dropped vertically before having been separated from

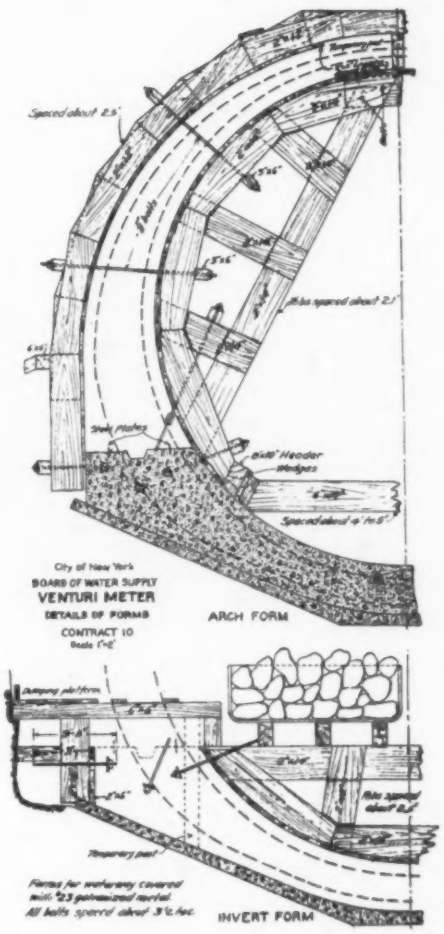


FIG. 20.—WOODEN FORMS FOR VENTURI METER NEAR ASHOKAN RESERVOIR.

the bottoms of the sides upward to the crown. This trouble seemed to be greater with slow hardening cements than with others. Peeling at the crown was prevented wherever the top of the form was cleaned, dried and lubricated just before placing the concrete in the top of the arch and where suitable care was taken in removing the forms. Removal of forms before the concrete had hardened sufficiently usually resulted in peeling, no matter what lubricant was used or what other precautions were taken. Thorough cleaning of the forms was found to be one of the most essential requirements for obtaining a good concrete surface, and other precautions failed if this detail were neglected.

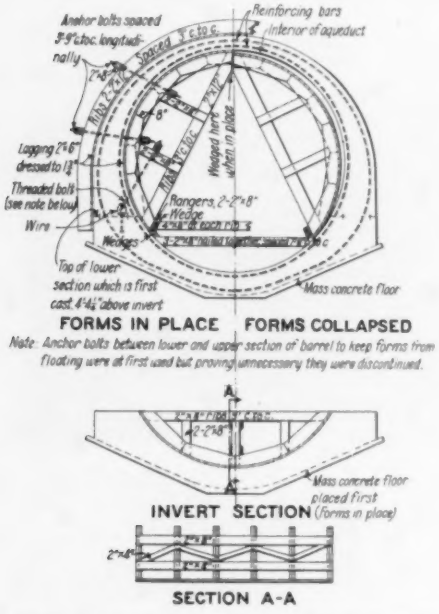

Anchor bolts spaced 3'-9" c.to c. longitudinally
Reinforcing bars
Interior of aqueduct
Spaced 1' 6 1/2" c. to c.
Hinged here
Hinged here when in place
Lagging 2"x6" dressed to 1 3/4"
Threaded bolt (see note below)
Wire
Rangers, 2-2"x8" @ each end
Wedges
Top of lower section which is first cast 4'-4 1/2" above invert
Mass concrete floor
FORMS IN PLACE
FORMS COLLAPSED
Note: Anchor bolts between lower and upper section of barrel to keep forms from floating were at first used but proving unnecessary they were discontinued.
2-2"x8"
Mass concrete floor placed first
INVERT SECTION (Forms in place)
2"x8"
SECTION A-A

FIG. 21.—WOODEN FORMS FOR PLEASANTVILLE VENTURI METER NEAR KENSICO RESERVOIR.

Improved Steel Forms for Cut-and-Cover Aqueduct.—By thorough study on the part of the engineers and contractors, as well as by the form makers, many improvements were effected as the result of the experience of the first season or two. Modifications of the Blaw inside form were designed and built for use during the second season of aqueduct construction (1910). These forms, Figs. 9 and 10, were similar in general design to the earlier Blaw forms except that $\frac{3}{16}$-in. plates were used, and many details of the connections between stiffening angles were worked out to better advantage. There was also much improvement in the workmanship resulting in corresponding improvement in the finish of the aqueduct surface. Interior bracing was still necessary, however, for the best results. In the use of the earlier

type of the form shown in Fig. 10 difficulty was experienced with the wooden carriage for moving forms, and so it was replaced by the electrically operated steel carriage here shown. The base of the carriage was a rigid steel car propelled by gearing. On the car was mounted a turn-table which supported an "A" frame and a platform containing the electric motors. These motors operated screw-jacks used in lifting and lowering the forms, also the propelling mechanism.

A new type of Ransome form, Fig. 11, made in 7½-ft. panels, having ¼-in. plate with five transverse ribs, three 5-in. I-beams and two 4-in. channels to each panel, was first used in 1910.

FIG. 22.—WOODEN FORMS USED IN THE CONSTRUCTION OF A REINFORCED CONCRETE VENTURI METER. THE 17-FT. DIAMETER APPROACH TO THE METER PROPER IS HERE SHOWN.

A hinge joint was provided at the top and in each side about 2 ft. above the invert. No wooden sill was used, the bottom of the form resting directly on the invert concrete. Wooden fillers were used for going around curves. These forms were designed to be telescopic with no interior bracing, but a transverse brace was placed at the joint between adjacent sections of arch.

Owego forms were modified in 1910 by substituting for the bolted joints 8 ft. above the invert, hinged joints placed 2 ft. above the invert. These forms were braced transversely by timbers at 5-ft. intervals at a height of 4 ft. above the invert.

A wooden sill was secured to the bottom of the form, on each side, and moved with the form.

Forms designed by the Stewart-Kerbaugh-Shanley Company, one of the contractors, and built by the Blaw Company, first used in 1910, were of a heavy type. The ribs were two 5 x 3 x $\frac{9}{16}$-in. angles and one 5 x 3 x $\frac{7}{16}$-in. intermediate angle to each 5-ft. panel, and were connected by horizontal angles spaced approximately

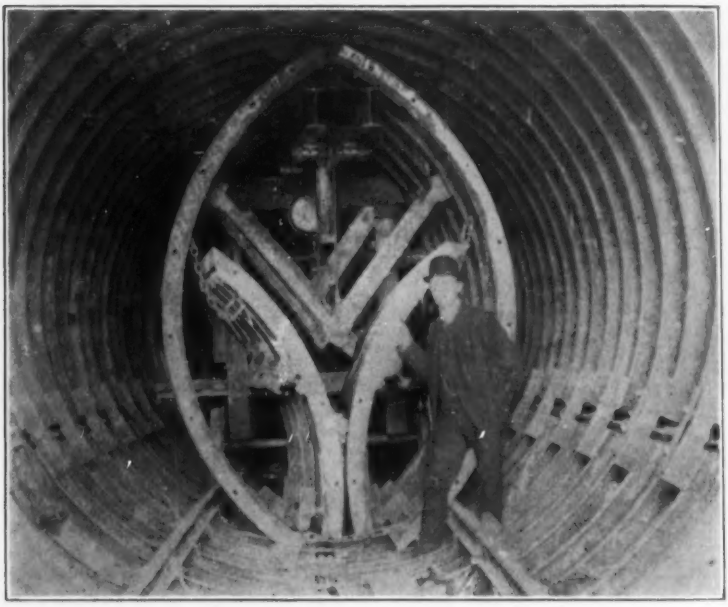


FIG. 23.—KENSICO BY-PASS, REINFORCED CONCRETE AQUEDUCT, 11 FT. IN DIAMETER, SHOWING INSIDE STEEL FORMS AND METHOD OF COLLAPSING AND TELESCOPING.

2½ ft. apart vertically. The plates were ¼ in. thick. The side hinge joints were placed about 2 ft. above the invert and heavily reinforced. These forms were at first used without transverse bracing, but it was necessary later to add pipe braces 5 ft. apart longitudinally and 4 ft. above the invert. This contractor also used a traveling concrete plant on one section, shown in Figs. 12 and 13.

Besides the other forms mentioned, a successful type was produced by King, Rice & Ganey and used for building about 11,200 ft. of aqueduct. These forms, shown in Fig. 14, were made of $\frac{1}{4}$-in. steel plate with a single hinge at the top and truss members from the hinge to the bottom spaced at 5-ft. intervals. The plate was stiffened longitudinally by purlins. These forms were of 5-ft. rectangular sections, the curves being obtained by

FIG. 24.—BLAW STEEL COLLAPSING FORM FOR 17-FT. REINFORCED CONCRETE EFFLUENT AQUEDUCT FROM KENSICO RESERVOIR. THIS FORM HAD A TOP AND TWO SIDE HINGES, THE SIDE HINGES ALLOWING THE FORM TO COLLAPSE WHEN THE BOLTS HOLDING THE INTERIOR VERTICAL BRACING WERE REMOVED.

wooden fillers. They were not telescopic and collapsed only enough to permit them to be moved through the completed arch. They rested on large wooden sills placed on the invert with wedges under each sill. Steel pipe braces with jacks at one end were used to prevent the sides from coming in during the placing of the concrete. These forms were struck by knocking out the wedges, then prying out the wood sills, and with steel wedges loosening the forms from the concrete, after which the side screw-

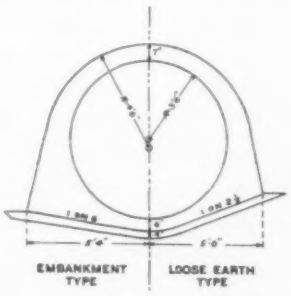
jacks were used to provide clearance to move ahead and to adjust the forms to line. A screw-jack on the carriage lowered the forms, which were then moved ahead, one 15-ft. section at a time. These proved to be the most efficient cut-and-cover forms from both the contractor's and engineer's viewpoint. Although they

FIG. 25.—BLAW FORMS FOR WALLKILL BLOW-OFF. THESE FORMS CONSISTED OF FOUR SECTIONS, THE INVERT TWO KEYS AND ARCH. THE INVERT SECTION HAS A HINGE ALONG THE CENTER LINE WITH SLOTS IN THE ANGLE ALONG THE EDGE FOR DRIFTING OUT BOLTS HOLDING A WEDGE PLATE BETWEEN THIS SECTION AND THE KEY SECTIONS. THE 6-IN. LONGITUDINAL KEY SECTION AND TWO HINGES OF THE ARCH SECTION ARE SHOWN. THE FOREGROUND SHOWS A CONCRETE CRADLE BLOCK FOR THE SUPPORT OF THE ENTIRE FORM. THE BACKGROUND SHOWS THE WOODEN LAGGING ATTACHED TO CHANNEL RIBS FORMING THE OUTSIDE FORMS.

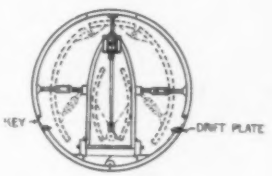
were a little heavier, and cost more, they were easily and expeditiously set up, collapsed and moved, at the same time being very rigid. They produced a very smooth interior surface, free from the sandiness characteristic of the telescoping forms, and were not appreciably distorted by the placing of the concrete.

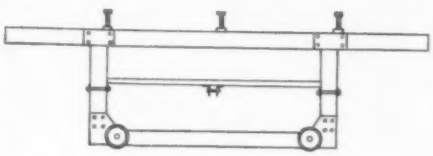
They were generally connected in 60-ft. lengths for concreting, the contractor having 195 lin. ft. available.

Trussing Sidewall Forms.—Early cut-and-cover steel forms as mentioned above were too flexible at the side joints. They were braced in some places by 6 x 6-in. or larger timbers near the joint level at about 5-ft. intervals, but these braces obstructed the passageway. Mr. Arnold Becker devised a system of trussing for Ransome steel inside forms used on that company's contract. This trussing system left the passage through the forms unobstructed. The arrangement is shown in Fig. 15. After 30 lin. ft. or more of forms had been set, a $\frac{5}{8}$-in. steel cable was rove through $1\frac{1}{4}$-in. holes in the I-beam ribs of the forms on each side about $6\frac{1}{2}$ ft. above the invert. Hickory posts, 6 to 8 in. in diameter, 7 ft. long, were set vertically on the invert through loops in the cables between ribs and about 5 ft. apart. The bottoms of these posts were blocked and wedged between the track ties and the forms. A 6 x 6-in. stringer just above the form joint was then wedged to each post after the slack in the cables had been taken up with the aid of the turnbuckles.



WALLKILL BLOW-OFF





WALLKILL BLOW-OFF

CAR USED IN MOVING INSIDE FORMS

B.W.S. 674

FIG. 26.—STEEL FORMS FOR REINFORCED CONCRETE WALLKILL BLOW-OFF. CAR USED IN MOVING INSIDE FORMS.

Advancing Cut-and-Cover Forms.—The two distinct classes of inside forms for cut-and-cover aqueduct necessitated quite dif-

ferent methods for advancing. With the telescoping forms the aqueduct progressed continuously in the same direction from any chosen point of beginning by "moving ahead," but with the King, Rice & Ganey and other non-telescoping forms, the "spacing-out" method was employed. This latter method required that the aqueduct be built backwards, although progression was, of course, forward. The forms were used in three sets, which were filled in 1-2-3 order, the concrete in No. 1 setting while Nos. 2 and 3 were being filled. No. 1 was then moved ahead 180 ft. and filled again. Next, No. 2 was moved ahead to meet No. 1, and was filled, after which No. 3 was moved ahead to meet No. 2.

FIG. 27.—EXTERIOR FORMS FOR PLACING THE CONCRETE JACKET ON STEEL PIPES, STEEL RIBS AND WOODEN LAGGING.

It was found impracticable to fit the steel end of the No. 3 set of forms into the end of the completed concrete aqueduct; accordingly a 5-ft. closure panel was made by using wooden lagging. The use of this wooden lagging for the closure panel was necessary each time because water-tightness of the forms could be secured in no other way; furthermore, the requirement that invert and arch joints correspond made the wooden panel necessary. "Spacing out" gave as good or somewhat better results and was the more generally used of the two methods during the last two years of cut-and-cover aqueduct construction, having some decided advantages over telescoping. Nevertheless, one contractor, using 300 lin. ft. of the older type of Blaw forms, which

had been discarded by another contractor, continued the telescoping method throughout the construction of three miles of aqueduct, obtaining good concrete surfaces and achieving the maximum monthly progress recorded, namely, 1740 lin. ft.

Outside Forms for Cut-and-Cover Aqueduct.—Outside forms for cut-and-cover aqueduct were a simpler matter by far than the inside forms. Two types of steel forms were first used, known

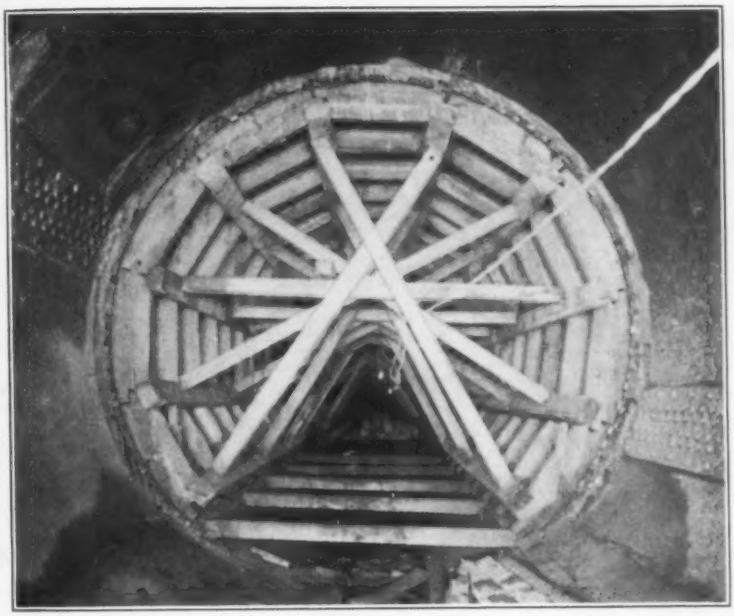


FIG. 28.—SECTIONAL WOODEN FORMS USED FOR LINING THE INTERIOR OF STEEL PIPE SIPHONS WITH 2 IN. OF CEMENT MORTAR. THESE FORMS WERE SEGMENTAL AND ALLOWED FOR SLIGHT VARIATIONS IN THE CROSS-SECTIONS OF THE STEEL PIPE.

as the Blaw and the Owego. Another early type, Fig. 16, consisted of steel ribs and wooden lagging of 2-in. shiplap held by steel stirrups with a wooden filler transversely across the forms at 15-ft. intervals. This type was used for about 20,000 lin. ft. of aqueduct in the Peekskill division. Objections to wooden lagging were the leakage and the cost of erection, neither of which proved serious. It had the decided advantage of being

better built up as the concrete was placed, thus affording better access for spading the concrete as deposited.

Early Blaw outside forms were built in small panels, of steel plate with angles at the edges, erected against stirrups 5 ft. on centers, and keyed up as the concrete was placed. This method

FIG. 29.—BLAW STEEL COLLAPSING AND TELESCOPING INSIDE FORMS, BULKHEAD AND CRADLE BLOCK FORMS FOR THE DIVIDING WALL AND BY-PASS AQUEDUCT OF THE HILL VIEW RESERVOIR. THIS INSIDE FORM CONSISTED OF TWO HINGES IN THE MIDDLE SECTIONS, THE INVERT AND ARCH. THE FORMS WERE MOVED ON A CAR WHICH RAN ON INVERTED ANGLES FASTENED TO THE INVERT FORM. THE TOP OF THIS CAR CONSISTED OF TWO CHANNELS EXTENDING BEYOND EACH END OF THE CAR AND SERVED AS A TRACK FOR CHAIN-BLOCK HOISTS WHICH COULD BE RUN OUT BEYOND THE BODY OF THE CAR ON THIS CANTILEVER. THE INVERT FORM WAS RAISED AT THE REAR OF THE CAR, RUN THROUGH ITS BODY AND DROPPED INTO PLACE ON CONCRETE INVERT BLOCKS SUPPORTING THE ENTIRE FORM. THE ARCH SECTION OF THE FORM WAS LOWERED ON TO SCREW JACKS MOUNTED ON THE CHANNELS AFTER HAVING BEEN DRAWN AWAY FROM THE CONCRETE BY TURN-BUCKLES ATTACHED TO THE CAR. THE BULKHEAD WAS OF STEEL PLATES STIFFENED BY ANGLE IRONS. ONLY THE LOWER PORTION OF THE DIVIDING WALL IS SHOWN.

proved slow, inconvenient and expensive, and was abandoned. Later Blaw forms, Figs. 17 and 18, were built in sections 15 ft. long, and were handled by a locomotive crane or other power device. These were rapid in handling and successful in every way. They were made of $\frac{3}{16}$-in. plate, edged by angles, and

held to the inside forms by tie bolts passing through the concrete. During concreting they were supported from the inside forms by blocks at 15-ft. intervals.

Owego outside forms, shown in Fig. 19, were built with trusses 5 ft. apart to make them self-supporting and do away with tie bolts. Sections of these forms were at first placed as the concrete was deposited, but toward the end of the work were built to full height in advance. They gave satisfactory results. The objections to them were that they were heavy and awkward to handle, and the trusses were in the way of the workman depositing the concrete, making it difficult to secure satisfactory finish on top of the aqueduct and to "spot" the buckets of concrete quickly. Tie bolts were sometimes necessary.

FIG. 30.—INTERIOR VIEW OF BLAW COLLAPSING AND TELESCOPING FORMS USED IN THE HILL VIEW BY-PASS AQUEDUCT, SHOWING THE CAR FOR MOVING FORMS.

Tie bolts or taper ($\frac{7}{8}$ to $\frac{3}{4}$-in.) rods between the inside and outside forms were almost universally used. They gave much trouble at first because not made of sufficient strength or because the number used was too small. Taper bolts and rods were more easily removed than those of one diameter. The number of bolts necessary depended somewhat upon the type of form employed, but ultimately it was found that $\frac{3}{4}$-in. bolts were satisfactory, provided at least five were used for each 5-ft. sec-

tion of form on each side of the aqueduct. In some places one $\frac{3}{4}$-in. and four 1-in. bolts were put into each section. At the ends of the forms set up for a day's work, special precautions were

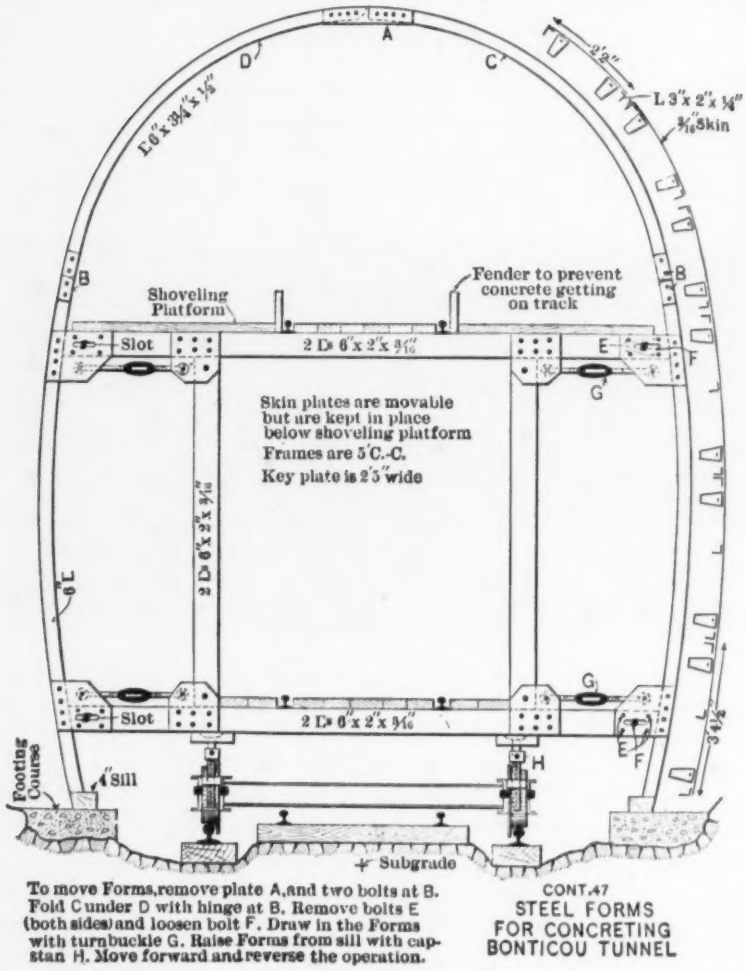


FIG. 31.—DETAILS OF BLAW STEEL GRADE TUNNEL FORMS FOR BONTICOU TUNNEL SOUTH.

necessary to prevent movement of the forms. The use of through tie bolts necessitated vigilance to see that the holes in the concrete were thoroughly filled with mortar after the removal of the forms.

Many of these holes escaped with insufficient filling during the first operations, and, being discovered later, were filled by special gangs of men working inside the aqueduct.

Bulkheads.—Bulkheads for closing the space between forms at the end of a day's work were important, since with them was combined the provision for water-stop in the resulting joint in the concrete. At first preference was given to a joint consisting of a tongue and groove, there being two grooves in the lower portion of the types of aqueduct having the thicker walls. The grooves were cast first. For this purpose the necessary projec-

FIG. 32.—COLLAPSING STEEL FORM FOR LINING GRADE TUNNEL. EACH RIB OF THE FORM HAD FOUR TURN-BUCKLES BY MEANS OF WHICH THE FORM WAS SLIGHTLY COLLAPSED. THE FORM WAS JACKED UP INTO PLACE FROM A CARRIAGE RUNNING ON RAILS. IT WAS SO DESIGNED AS TO ALLOW THE PASSAGE OF CONCRETE CARS TO FORMS BEYOND.

tions were placed on the bulkhead. Some of the bulkheads were made of wood and braced in position from the sidewall foundations, but most of them were of steel plate. Both wood and cast-iron molds were used for forming the key grooves. Wooden molds covered with sheet metal were discarded in a short time because they were difficult to draw. The cast-iron molds were more successful. Ultimately, however, this type of joint was abandoned for a number of reasons and a steel plate 6-in. wide and about $\frac{3}{8}$-in. thick, used as the water-stop, being imbedded half its width in the concrete first placed. To expedite the removal of the

bulkheads so that the erection of forms for the next section of concrete could proceed promptly, hardening of the concrete was hastened by one or two contractors, during the colder periods,

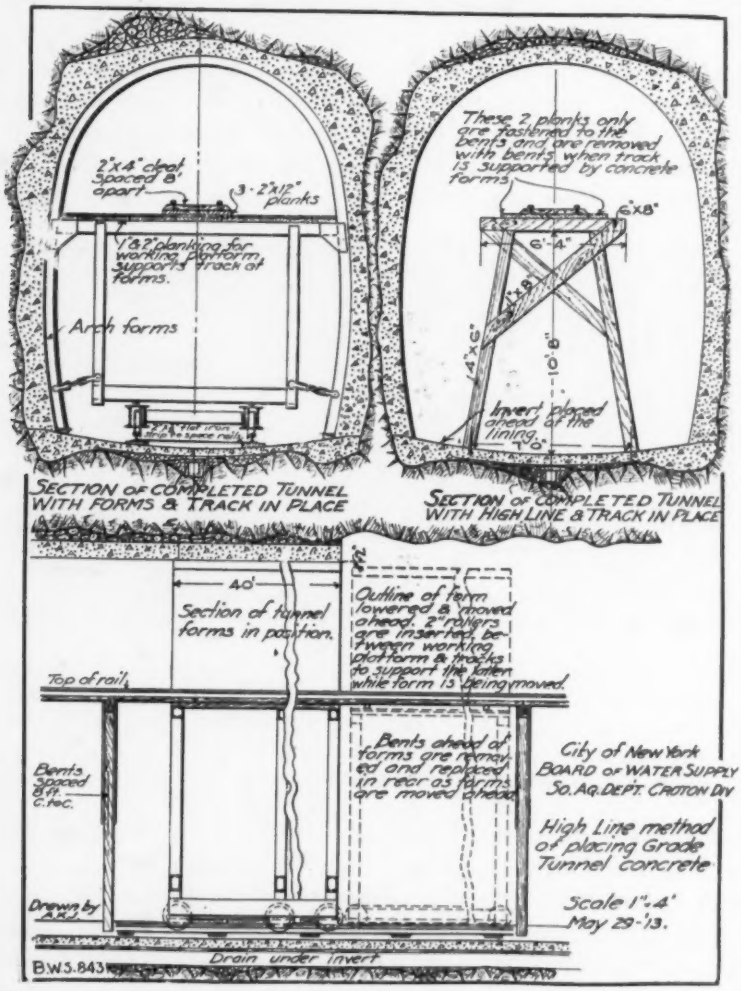

2"x4" cleat spaced 8' apart
3-2"x12" planks
1"&2" planking for working platform supports track of forms.
Arch forms
These 2 planks only are fastened to the bents and are removed with bents when track is supported by concrete forms.
6"x8"
6'-4"
4"x6"
10'-8"
Invert placed ahead of the lining.
SECTION OF COMPLETED TUNNEL WITH FORMS & TRACK IN PLACE
SECTION OF COMPLETED TUNNEL WITH HIGH LINE & TRACK IN PLACE
40'
Section of tunnel forms in position.
Outline of form lowered & moved ahead. 2" rollers are inserted between working platform & tracks to support the latter while form is being moved.
Top of rail
Bents spaced 8 ft. c. to c.
Bents ahead of forms are removed and replaced in rear as forms are moved ahead.
City of New York
BOARD OF WATER SUPPLY
SO. AQ. DEPT. CROTON DIV
High Line method of placing Grade Tunnel concrete
Scale 1"=4'
May 29-'13.
Drawn by A.H.J.
B.W.S. 843
Drain under Invert

FIG. 33.—"HIGH LINE" OF GRADE TUNNEL FORMS AND TRACKS.

by means of steam pipes placed next to the bulkheads. This permitted removal of the bulkheads a few hours after the concrete had been placed.

Forms for Reinforced Concrete Aqueduct.—There are several stretches of aqueduct of heavily reinforced concrete, including three Venturi meters, which are probably the largest in the world. (See Figs. 20, 21 and 22.) Kensico by-pass, circular,

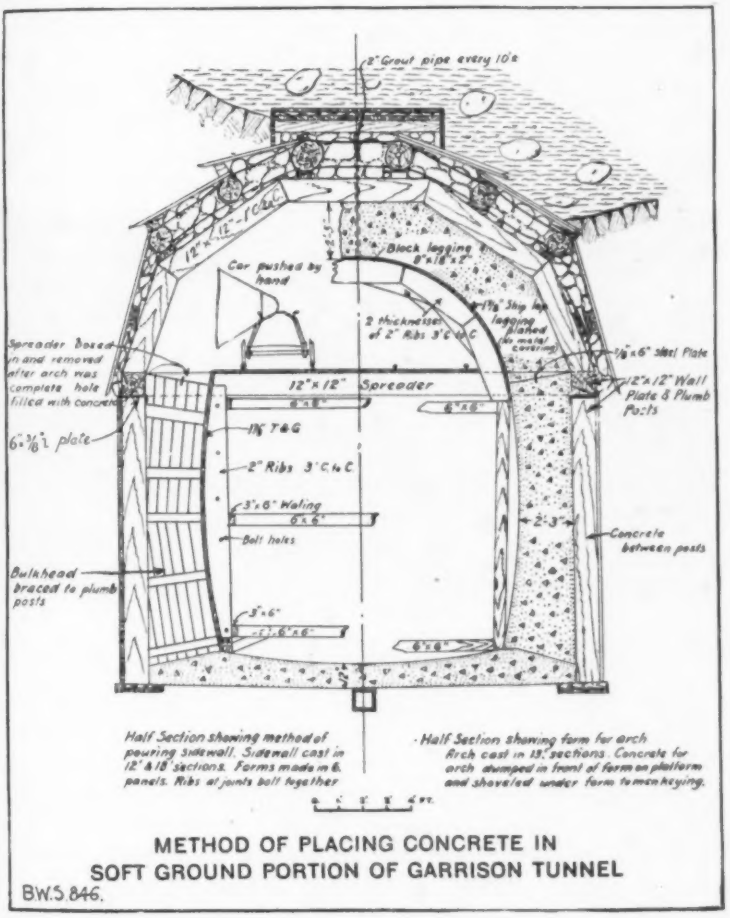

2" Grout pipe every 10'
Block lagging 8"x18"x2"
Car pushed by hand
1½" Ship lap lagging planed (no metal covering)
2 thicknesses of 2" Ribs 3'C to C
Spreader Boxed in and removed after arch was complete hole filled with concrete
12"x12" Spreader
6"x6"
6"x6"
6"x6" plate
1½" T&G
2" Ribs 3'C to C
3"x6" Waling
6"x6"
Bolt holes
Bulkhead braced to plumb posts
3"x6"
6"x6"
6"x6"
6"x6" steel Plate
12"x12" Wall Plate & Plumb Posts
2'-3"
Concrete between posts
Half Section showing method of pouring sidewall. Sidewall cast in 12' & 18' sections. Forms made in 6 panels. Ribs at joints bolt together
Half Section showing form for arch. Arch cast in 18' sections. Concrete for arch dumped in front of form on platform and shoveled under form to make keying.
METHOD OF PLACING CONCRETE IN SOFT GROUND PORTION OF GARRISON TUNNEL
BW.S.846.

FIG. 34.

11-ft. inside diameter, 11,000 ft. long, is one of these stretches. It was built with cylindrical steel inside forms. A 4-in. layer of lean concrete was first placed on the trench bottom. On this layer special cradle blocks were built, 7½ ft. apart, to support

the inside forms and part of the reinforcement. After the reinforcing rings had been threaded over the inside forms and the latter placed on the cradle blocks in exact position, the rings were spaced properly and the longitudinal rods wired to them. Then the outside forms were placed. At the beginning of this work, heavy ballast was placed inside the form to prevent flotation in the liquid concrete. It was soon learned, however, that little or no ballast was needed because the weight of the form and of the reinforcing steel, which was supported by it, sufficed.

In the early work much imperfect concrete was found, espe-

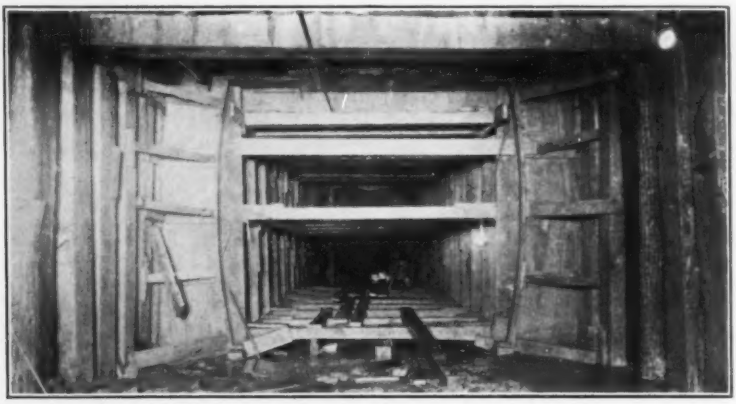


FIG. 35.—WOODEN SIDEWALL FORMS USED IN LINING A PARTICULARLY DIFFICULT STRETCH OF GRADE TUNNEL PASSING THROUGH UNSTABLE MATERIAL. THE ARCH LINING WAS PLACED AFTER THE SIDEWALL CONCRETE HAD SET.

cially in the invert, due to the type of outside form used. These forms were solid with the exception of a panel every 7.5 ft. on each side, 3 ft. wide and 4 ft. 3 in. high, through which the concrete was placed. This arrangement of forms made portions of the concrete, particularly at the invert, difficult of access for spading.

An improvement was suggested by making the steel ribs in halves, bolted together at the top, with a longitudinal separator. I-beams, or double channels back to back, would be suitable for the ribs. At their bottoms the ribs should be spaced and secured

by a longitudinal plate, about 1 ft. high, which would serve as the first course of lagging. For the lagging, planks about 8 in. wide, cut to suit the distance between centers of ribs, would be suitable. Each piece of lagging should have on its lower edge a 2 x $\frac{1}{8}$-in. steel plate, fastened on to the outside face with wood screws, and projecting about 1 in. If necessary for tightness, a strip of cotton packing could be nailed to the lower edge of each lagging board. With the plate on the lower edge of the lagging, the top edge is more rapidly cleaned and the plate is not exposed to injury while placing the concrete. The lagging

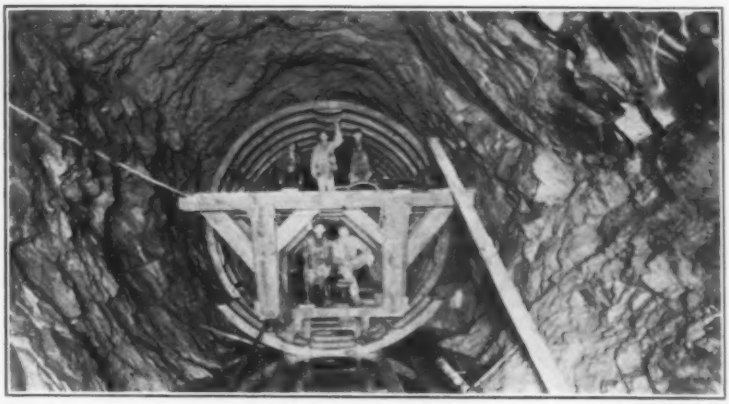


FIG. 36.—EARLY TYPE OF RANSOME FULL-CIRCLE PRESSURE TUNNEL FORM. THE ARCH PORTION WAS MOVED FORWARD ON A WOODEN CARRIAGE RUNNING ON RAILS SUPPORTED ON THE INVERT PORTION OF THE FORM. TWO SIDE JOINTS AND ARCH JOINT ARE SHOWN.

boards should rest against the inside of the ribs and be held in place by a hardwood or metal button at each end. Such lagging could be handled by one man.

Several illustrations show forms used for reinforced concrete aqueduct. For Kensico by-pass (Fig. 23) the forms were of Ransome make, collapsible and telescopic. They were modified in several details after the first season's use. Inside forms weighing 650 lb. per lin. ft., had four joints,—at the crown, at the center line of the invert, and in each side, 5 ft. from the invert center line. They were made up of 5-in. angle and 5-in. channel

ribs, with $\frac{1}{4}$-in. plates, in sections $7\frac{1}{2}$ ft. long, one channel being at each end and the angles between. A concrete block was set under the center of each inside form. The carriage for collapsing and moving the forms traveled on a track built permanently in the lower part of the forms. This carriage was propelled through sprockets and chains by a hand crank. A pair of 8-in. I-beams connected by plates and secured horizontally at the top of the

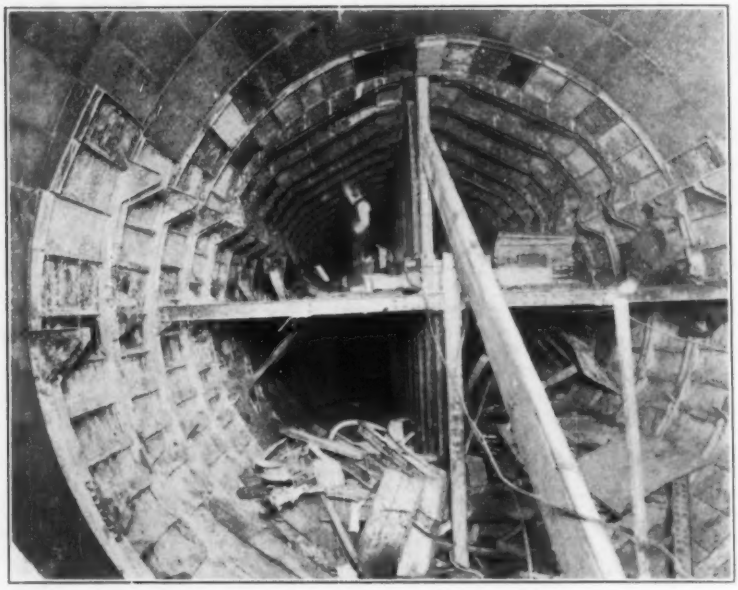


FIG. 37.—PRESSURE TUNNEL FORM DESIGNED BY THE CONTRACTOR, GEORGE W. JACKSON, INC. LAGGING WAS BENT TO THE THEORETICAL RADIUS AND PLACED AS THE CONCRETE ROSE BEHIND THE FORM. BEFORE PROCEEDING WITH THE SIDEWALL AND ARCH LINING, THE INVERT FOR A WIDTH OF 7 FT. WAS PLACED AND THE FORM SET UP ON IT.

carriage, projected 8 ft. beyond the carriage frame. Under these I-beams were two sheaves, depending from which by cables were arms which engaged the forms for lifting and moving them. The cables ran to a winch on the rear of the car, operated by four men. Outside forms for this portion of the aqueduct were in two parts and when set up for concreting had a space 6 ft. wide between their tops. The weight of these outside forms per linear foot of

aqueduct was 500 lb.; they were made of No. 10 gage steel plate with 4-in. channels having $\frac{1}{4}$-in. web and $1\frac{1}{2}$-in. flanges as ribs at each end of the $7\frac{1}{2}$-ft. section, with two 2 x 2 x $\frac{3}{8}$-in. angles between, the space between the angles being greater than that between each angle and the adjacent channel. These sections were handled by a locomotive crane. Special tapered steel fillers were used on curves in the aqueduct. Bulkheads for the ends of day's work were of steel, bolted around the inside form and to the end of the outside form. A slot $\frac{3}{4}$ in. wide for the $\frac{1}{2}$ x 6-in. expansion joint steel plate was formed between the portion of the bulkhead next to the inside form and the outer portion. The inner portion of the bulkhead was a 7-in. channel bent to a circle, with its flanges outstanding. The outer portion of the bulkhead was of $\frac{1}{8}$-in. steel plate, edged with $2\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{3}{16}$-in. angles. Both portions were made in nine segments for convenience in handling one at the bottom and four on each side with a joint at the crown. Inside and outside forms were connected by means of tapered bolts. All these and other bolts for connecting parts of forms were made with high-pitch threads for quick action. The concrete cradle blocks for supporting the inside forms were cast in steel forms, set up on the lean concrete bottom layer of the aqueduct. Because the top surface of each cradle block became a part of the aqueduct invert, the block forms had to be set very accurately. No lubricant was used on the block forms.

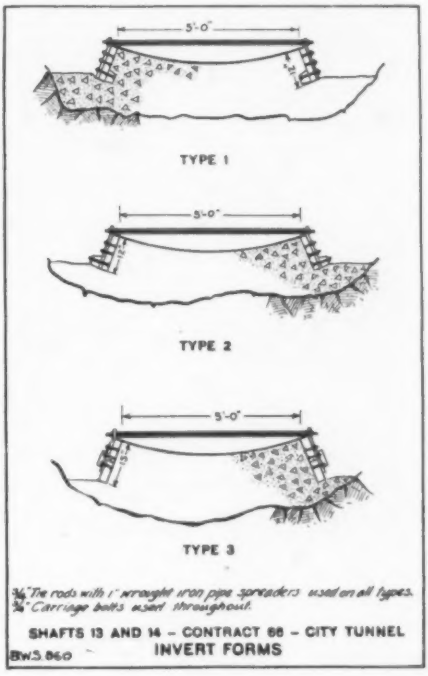


FIG. 38.

An interesting and successful type of form, shown in Figs. 25 and 26, was evolved in the construction of the Wallkill blow-off, a reinforced conduit of 7 ft. inside diameter. The inside forms consisted of four parts, the bottom with a width of approximately 3 ft. either side of the invert center line, two key pieces about 6 in. wide, and the arch section comprising the remainder of the circle. These forms were built up of $\frac{1}{8}$-in. plates riveted to 6 x 2 x $\frac{1}{4}$-in. channels, spaced transversely 18 in. center to center, making four to each 5-ft. section. Along the center line of the bottom form a hinge joint was provided so that it could be folded

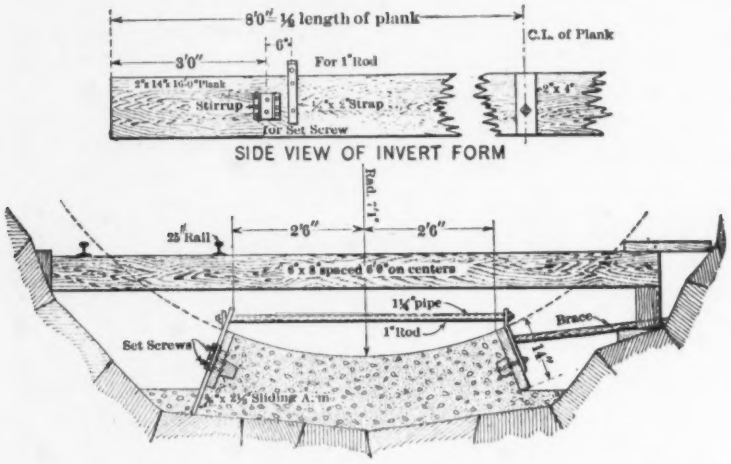


FIG. 39.—DETAILS OF CONTINUOUS INVERT FORM FOR PRESSURE TUNNELS. ALSO "HIGH LINE" FOR PLACING CONCRETE DIRECTLY FROM CARS.

in halves. Two $2\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{1}{4}$-in. angles were placed 14 in. either side of the center line for a track upon which to run the erection car. The arch form had two longitudinal hinge joints one foot either side of the center. The 6-in. longitudinal keys fitted on either side between the two main parts of the form, and were joined to the arch by 2 x 3 x $\frac{1}{4}$-in. angles with the 3-in. leg outstanding. Each joint between a key and the lower form was made by two special 3 x 5 x $\frac{1}{4}$-in. angles with the 5-in. leg outstanding, having between them a loose plate 6 in. x $\frac{1}{4}$ in. x 5 ft., which extended into the inside of the form. This plate had a number of holes drilled in it at various distances from the edge

by means of which it could be drifted out, thus giving enough clearance to permit the keys to be removed.

The hinge joints were formed of triangular plates extending into the form and turning on a 1-in. bar, which was about 5 in. from the face and extended the entire length of the form. Two-

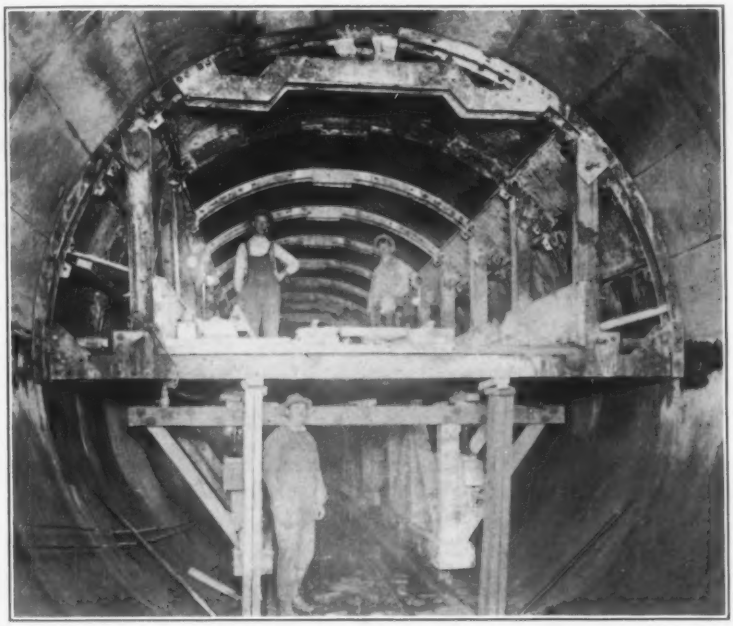


FIG. 40.—EARLY BLAW TYPE OF PRESSURE TUNNEL FORM IN POSITION FOR PLACING CONCRETE FOR TUNNEL ARCH. A WOODEN CARRIAGE RUNNING ON RAILS SUPPORTED THE FORM. THE FORM WAS JACKED UP INTO PLACE FROM THIS CARRIAGE AND BRACED AS MUCH AS POSSIBLE. AS THE CONCRETE BEHIND THE FORM ROSE, ADDITIONAL PLATES WERE FASTENED TO THE FORM RIBS. THE FORM WAS CLEARED FROM THE CONCRETE BY PULLING IN ITS SIDES WITH TURN-BUCKLES AND WAS LOWERED BY SCREW-JACKS.

in. x 3-in. x $\frac{1}{4}$-in. angles attached to the face of the form at each joint were bolted together when the section was set up, thus locking the joint shut. Gusset plates riveted to the channels afforded attachment for the screw jacks used in handling the forms.

For moving the forms there was a car which consisted of two 6 x 2-in. channel "A" frames mounted on a four-wheel truck, 10 ft. 6 in. long, and carrying at the top two 8 x 2-in. channels about 18 ft. long. These channels were spaced 15 in. apart and served as rails for a trolley which picked up the bottom section of the form from behind by means of the overhanging end. After the form had been folded, the trolley ran it through the "A" frames out on to the cantilever channels ahead, from which it was lowered into place. Three jacks on each side and three on top served to collapse and erect the arch section of the forms.

In moving ahead the sequence of operations was as follows: The 15 ft. of extra bottom forms which protruded beyond the arch were taken up first, 5 ft. at a time, run into the car and

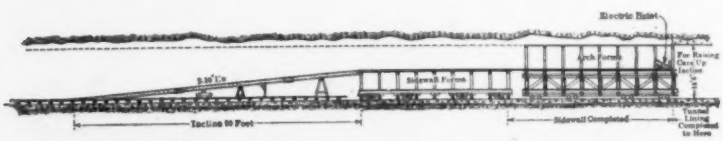


FIG. 41.—TRAILING SIDEWALL AND ARCH FORMS, AS USED FOR WALLKILL PRESSURE TUNNEL. ALSO LATER FOR RONDOUT, MOODNA, CROTON AND CITY AQUEDUCT TUNNELS. BY THIS METHOD, PROGRESS WAS MUCH INCREASED OVER THE SEPARATE USE OF SIDEWALL AND ARCH FORMS WITH CORRESPONDING ECONOMY.

lowered on to the truck. With these three sections the car was taken ahead, the forms set up by running each 5-ft. piece on to the projecting channels and lowering them on to the small concrete pedestal blocks provided for them. As fast as a piece was set, the car was run out on it and another placed. These three sections of bottom having been bolted fast, the car was taken back and 15 ft. of arch forms taken down. First the top jacks were brought to bear against the crown, and the filler plates drifted out, permitting the keys to be removed. By means of the side jacks, the sides were then pulled free from the concrete and the whole section lowered sufficiently to clear the forms still in place. Finally the car was moved ahead on the bottom sections previously set up, the jacks extended and the drift plates and keys inserted between arch and bottom. Each longitudinal key and hinge joint had four $\frac{5}{8}$-in. bolts, and the transverse joints

had sixteen. For each 15 ft. of forms moved, 28 bolts had to be removed from the longitudinal joints and 16 from the transverse joint.

The outside forms consisted of 6 x 2 x $\frac{1}{4}$-in. channel ribs, to which $1\frac{7}{8}$-in. ship-lap lagging was attached as the concrete advanced. The upper portion was an arch and was available for all types while a joint a little above the springing line provided means for attaching extension legs to conform with the required type of structure. These ribs were spaced about 5 ft. apart and were braced against the side of the excavation, doing away with rods or wires in the concrete, except on embankments. A timber

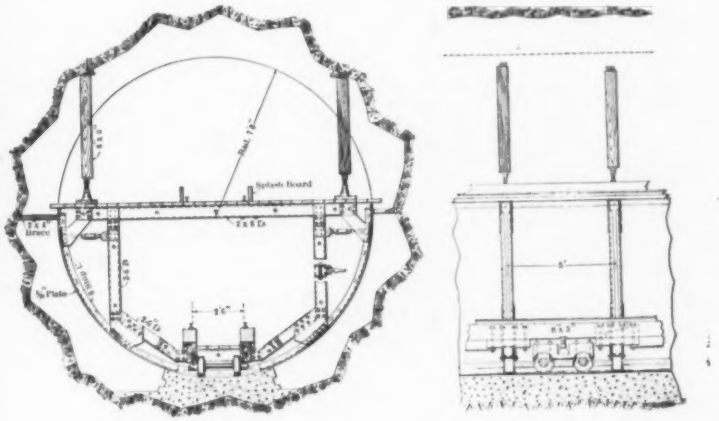


FIG. 42.—PRESSURE TUNNEL SIDEWALL FORMS, WORKING PLATFORM AND CARRIAGE. COMPLETED CONCRETE INVERT SHOWN.

bulkhead was erected at the end of each day's work between the inner form and an outer rib. These forms were furnished by the Blaw Collapsible Steel Centering Company.

FORMS FOR LINING STEEL PIPES.

For jacketing the steel pipes with concrete, the most interesting precaution was the filling of the pipe with water to full service pressure before beginning to place concrete and keeping it under this pressure until the concrete had hardened, thus avoiding the troubles which would have resulted from changes

of shape if the concrete had been placed around the empty pipe. The outside forms consisted of simple ribs of about 3 x 3-in. angles, spaced 5 ft. apart, connected by small steel channels across the top of the pipe, and wooden lagging cut to fit between the ribs. These forms and the method of placing concrete as used on one of the pipes is shown in Fig. 27.

Lining the steel pipes with mortar to a thickness of about 2 in. at the thinnest spots, presented some unusual problems. This lining was done after the jacket had hardened. It was desirable to have the mortar adhere to the whole surface of the

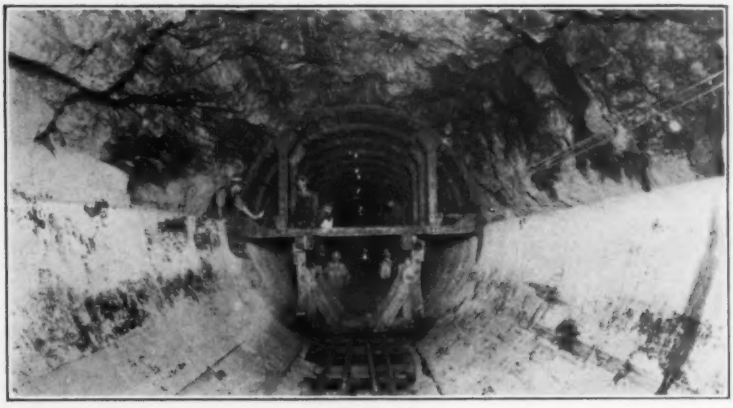


FIG. 43.—IMPROVED STEEL FORMS FOR LINING 15-FT. PRESSURE TUNNEL IN THE CITY AQUEDUCT. THESE ARE TYPICAL OF THE FORMS USED FOR ALL SIZES OF PRESSURE TUNNEL UNDER THE LATER CONTRACTS.

pipe, or as nearly so as feasible. The mortar when hardened, must be dense and strong and have a smooth surface. To accomplish these ends a mandrel, or complete cylindrical form, was suggested but found impracticable. Collapsible steel forms were designed to meet the following conditions:

1. The form must be collapsible to such an extent that the entire outside surface of the form could be thoroughly examined, cleaned and lubricated after each use, without removing it from the pipe.

2. It must be stiff enough to resist distortion while the grout was being poured and was setting.

3. It must be flexible or adjustable, so that it could be accommodated to the varied cross-sections of the pipe. This was an important consideration, particularly near the ends of each pipe, where the internal pressure of the water was not sufficient to force the steel pipe to a circular shape, as in the portion under greater pressure at the bottom of the valley.

Designs for a steel form were taken up by one of the contractors with the Ransome Concrete Machinery Company, which made a short length of forms for trial. This form was never used, as inspection showed it to be too stiff to answer the third

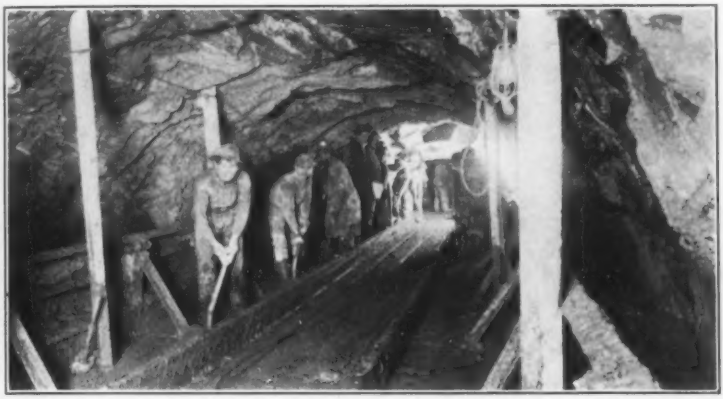


FIG. 44.—LATER FORM FOR LINING PRESSURE TUNNEL, SHOWING CONCRETE BEING PLACED IN THE TRAILING ARCH FORM IN THE BACKGROUND, AND THE SIDEWALL FORM IN THE FOREGROUND.

requirement. Another contractor obtained 7 ft. of steel forms from the Blaw Collapsible Steel Centering Company which were experimented with, but likewise found too cumbersome and insufficiently flexible to be adapted to the varied shape of the pipe. Other considerations which militated against the use of a complete cylindrical steel form were the difficulty of getting such a form around vertical or horizontal curves and of collapsing one section sufficiently to pass through another which was still in place during the hardening of the grout.

Subsequently, wood forms of the type shown in Fig. 28 were made and found satisfactory. These forms were built care-

fully in panels about 15 ft. long and 2 ft. wide, with a mortise-and-tenon joint for connecting adjacent panels. For some of the curves in the pipes, panels $7\frac{1}{2}$ ft. long were used. None of these forms was covered with sheet metal, but the lagging was of hard pine. Owing to the comparative narrowness of the panels, the forms could be adjusted to the shape of the pipe and the required thickness of lining secured by the use of cast-iron separator attached to the lagging. Radial wood struts were used to brace the forms when set up. A dense, smooth surface was secured and the forms were used repeatedly, although without the metal covering. Previous experience with sheet-metal-

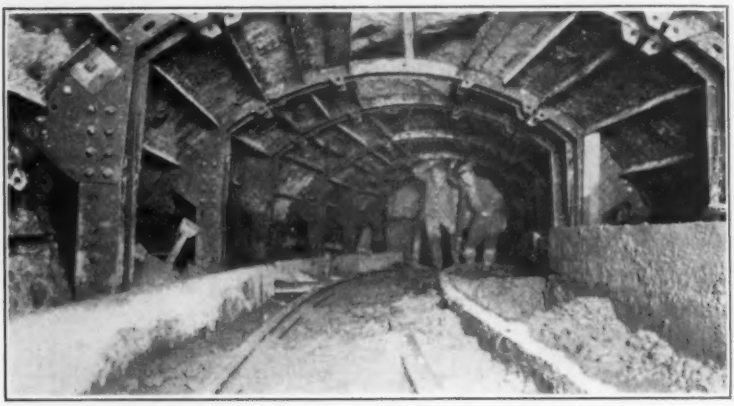


FIG. 45.—BLAW ARCH FORM ON CURVE FOR LINING PRESSURE TUNNEL. ALL THE CONCRETE WORK EXCEPTING THE KEYING OF THE ARCH AT ITS CROWN HAS BEEN COMPLETED.

covered forms of the engineers in charge of this work had not been satisfactory owing to the fact that the metal had become wrinkled and cracked with repeated using of the forms. On the Weston aqueduct, for the Metropolitan Water supply of the Boston district, wooden forms, covered with galvanized sheet steel, were, however, used very successfully in forming the arch of the 13 miles of cut-and-cover aqueduct and for the concrete lining of 2 miles of tunnel.

In lining a pipe, the first step was to cover the invert by methods similar to those of concrete sidewalk construction. At first inverts covering 8 ft. 10 in. of arc, were used, but difficulty

was experienced by their edges separating slightly from the pipe. To obviate this trouble, narrower inverts were used, widths of 2 to 5 ft. being found successful. For the remainder of the lining, the space between the form and the pipe was filled by pouring grout through 2-in. pipes which extended through the concrete jacket and the steel plate.

FORMS FOR GRADE AND PRESSURE TUNNELS.

Forms for grade and pressure tunnels had to satisfy the requirements for the cut-and-cover forms and in addition had to

FIG. 46.—GALLOWS FRAME FOR RAISING INCLINE LEADING TO TOP OF FORM. THIS ARRANGEMENT ALLOWED THE PASSAGE OF CONCRETE CARS THROUGH THE LOWER PORTION OF THE FORM TO OTHER POINTS ALONG THE TUNNEL WHERE CONCRETING WAS GOING ON.

be so arranged that traffic in the tunnels could be maintained through them. Furthermore, the space in which all the operations must be performed was closely restricted by the size of the tunnel excavation. In the 11-ft. tunnel constituting the lower end of the City tunnel, these restrictions as to space became the important element of many construction problems. Indeed, this minimum diameter of the tunnel was determined largely by the requirements for construction operations. Provisions for grouting, protection of the newly-placed concrete against water entering from the roof and sides of the tunnel in some places, and the

presence of tunnel support, complicated the manipulation of forms and other concreting operations.

Grade Tunnel Forms.—Forms for the twenty-four grade tunnels, totaling 14 miles, were of steel and made by the Blaw Company. They are clearly shown in some of the illustrations. Like the cut-and-cover forms, the earlier grade tunnel forms were of insufficient strength and rigidity. The Blaw forms used later were made of plates $\frac{3}{16}$ in. thick, with ribs spaced 5 ft. center to center, of 6 x $3\frac{1}{4}$ x $\frac{1}{2}$-in. channels above and below the working platform, which was approximately at the level of the springing line of the arch. Other details of these forms are shown by some of the accompanying illustrations. (See Figs. 31 and 32.)

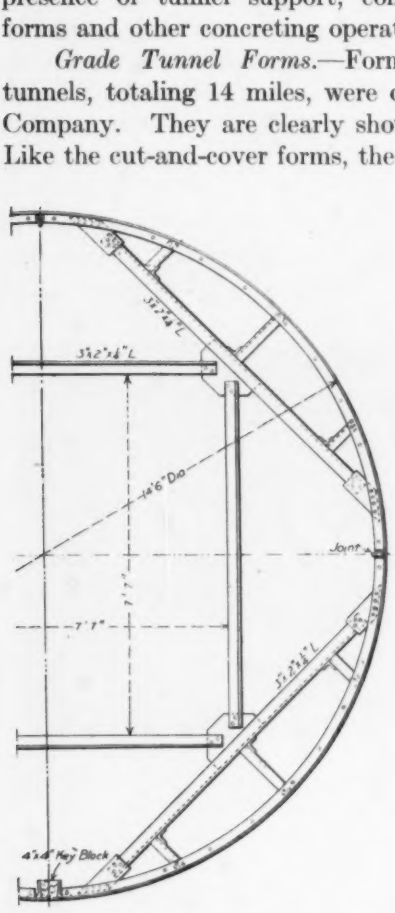


FIG. 47.—HALF PLAN OF STEEL SHAFT FORMS.

In concreting grade tunnels a footing course was commonly built first accurately to line and grade at the bottom of each side of the tunnel to support the form for the sidewall and arch. These footings were of various shapes according to the ideas of the contractors. Concreting the invert between these footing courses was usually the last operation. In each short tunnel, or in each part of a long tunnel concreted separately from a portal or shaft, three sets of sidewall and arch forms were provided and set at such distances apart that the portions of tunnel allotted to the three sets of forms would be completed in the same time. This arrangement made it possible to do concreting in some one of the forms every day while the concrete in another was hardening and the third form was being moved and set up. Owing to

the shape of the tunnel cross-section, the sidewall portions of the forms were nearly straight; this made it the more difficult to hold them to shape and line. Because the concrete lining usually was thin, the forms were filled rapidly and the pressure of the liquid concrete on the form was correspondingly great. The working platform afforded some stiffness, but the necessity for transportation through the form prevented bracing except at

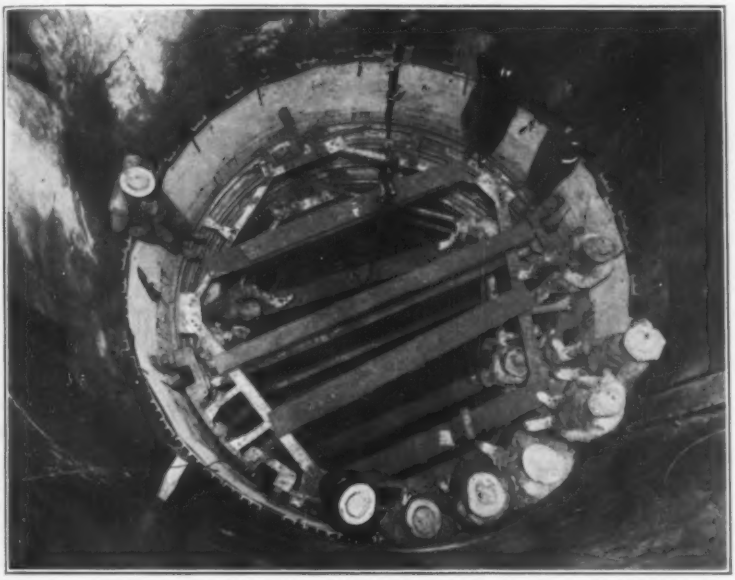


FIG. 48.—VIEW LOOKING DOWN A SHAFT, SHOWING THE COLLAPSING STEEL FORMS FOR LINING A DRAINAGE SHAFT. OBSERVE GROOVED TERRA-COTTA TILE INTER-LINING, CONCRETE OUTER-LINING AND CAST-IRON FORMS FOR VERTICAL CONCRETE GUIDES.

the track level. In the grade tunnels built under some of the later contracts east of the Hudson River, the tracks for the concrete cars were supported on a trestle approximately at the elevation of the springing line of the arch, as shown in Fig. 33. This arrangement was designated the "high line" method and proved economical and convenient. For most of the tunnels, form units long enough to line 30 ft. of tunnel were used, but in at least one tunnel the forms were 40 ft. long, and it was the

opinion in the later stages of the work that longer forms could have been used satisfactorily.

On account of the difficulty experienced in timbering 680 ft. of Garrison grade tunnel through soft, disintegrated rock overlain with sand and boulders, wooden forms of the construction shown in Figs. 34 and 35 were used for the concrete lining. The invert was laid first. Wooden forms were necessary on account of the presence of 12 x 12-in. spreaders spaced from 12 to 16 ft. apart, which were left in place between posts of the tunnel timbering during the concreting operations. These spreaders were necessary owing to the heavy pressure taken up by the tunnel timber roof and sidewall supports. Where the spreaders passed through the concrete lining they were boxed in, and the holes left upon their removal were later filled in with concrete. Sidewall and arch forms were built separately. Three sets of wooden sidewall forms, each made of two 6-ft. panels, were employed. These reached to about the springing line of the arch. After the sidewalls had been completed, the arch forms, supported by posts, were put in place and the arch concrete placed. The forms for the sidewalls were made of 2 x 12-in. ribs, spaced 3 ft. center to center, covered with $1\frac{7}{8}$-in. tongue-and-groove lagging 6 ft. in length. Sidewall forms were held in place by 6 x 6-in. inside bracing and walling pieces, to insure proper alignment. Arch forms were made up of 4-in. segmental ribs 3 ft. center to center, covered with $1\frac{7}{8}$-in. lagging 13 ft. in length.

Forms for Pressure Tunnels.—All the pressure tunnels, aggregating 35 miles in length, are circular in cross-section. Their diameters range from 11 ft. in the Brooklyn and lower Manhattan portions of the City tunnel, to 16 ft. 7 in. in the Yonkers pressure tunnel, just north of Hill View reservoir, which is near the City boundary. The pressure tunnels north of this reservoir are 14 to $14\frac{1}{2}$ ft. in diameter. For lining all these tunnels with concrete three types of steel forms were used,—Blaw, Jackson and Ransome. Wooden forms were used for quarter-bends connecting tunnels with shafts and for other special connections. So far as known, previous to the Catskill aqueduct work, in all tunnels in this country which have been lined with concrete, wooden forms have been used. At the beginning of the Catskill aqueduct pressure tunnel work, an endeavor was made to devise

a cylindrical steel form by means of which the lining could be cast monolithically for the whole periphery of short sections of the tunnel. These forms were made in parts which could be disconnected and carried forward to be re-erected for the next section of concreting. Furthermore, the concrete cast with them was not satisfactory, it being particularly difficult to get the invert solid and smooth.

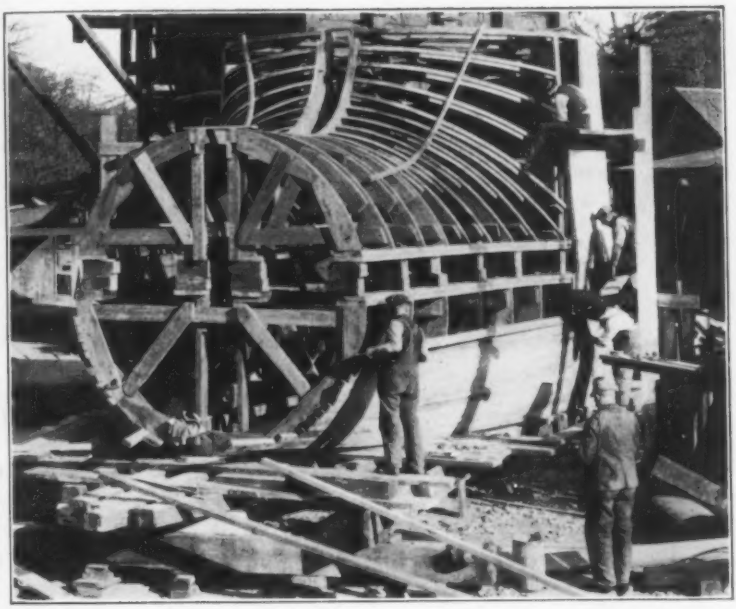


FIG. 49.—WOODEN FORM FOR QUARTER-BEND AT THE BOTTOM OF A WATERWAY SHAFT LEADING TO A PRESSURE TUNNEL. THIS TYPE OF FORM WAS MADE IN SECTIONS ON THE SURFACE OF THE GROUND FOR ASSEMBLING AT THE BOTTOM OF THE SHAFT.

In using the Ransome full-circle forms, an invert 5 ft. wide was cast in advance. These forms are shown in Fig. 36. They were built in 5-ft. sections, each such section having three ribs, a 5-in. channel at each end and a 5-in. I-beam in the middle. Adjacent sections were bolted together through the channel ribs. All plates were $\frac{1}{4}$ in. thick. A carriage with a steel frame supporting two windlasses, with gears and steel cables, and twelve

cantilever arms, was provided for collapsing, moving and resetting 30 ft. of forms at a time. The forms were well made, but some of the parts fitted too closely, making it difficult to re-assemble them. The greatest trouble in this respect was with the key-plates at the top of the tunnel. After the forms had been set up, a heavy wooden working platform, traveling on a track, was moved into the forms, and from this platform the concreting was done. This platform is shown in Fig. 36. A 12-H.P. electric hoist on the rear of this platform drew a three-car train up an 88-ft. steel incline from the tunnel track in front of the form.

It was soon demonstrated that the pressure tunnels of the Catskill aqueduct were too large to be economically concreted for the full section in one operation. The full-circle forms proved costly to collapse, move and prepare again for concreting, and the placing of the concrete was slow. It was found desirable to have a minimum spacing of ribs of about 5 ft., as few plates as possible to be attached during concreting, and as few bolts as may be for use in collapsing or attaching plates. Plates should have at least $\frac{1}{8}$-in. clearance at joints. For the reasons suggested, this type of form was abandoned for the semi-circular type.

Yonkers pressure tunnel, extending 11,200 ft. northerly from Hill View reservoir, is 16 ft. 7 in. in inside diameter. The Jackson forms (Fig. 37), used for 10,000 ft. of this tunnel were unlike those in any other tunnel of the aqueduct; they consisted of complete circular ribs of 5-in. steel I-beams, or two 5-in. channels riveted together. The lagging was of $\frac{1}{8}$-in. steel plates, 1 x 3 ft., stiffened by $1\frac{1}{2}$ x $1\frac{1}{2}$-in. steel angles near the edges. The ribs were set up 3 ft. apart and the lagging plates placed upon them just in advance of the concrete, course by course. About 90 lin. ft. of these forms were provided for each place where concreting was in progress. As the concrete hardened, forms were taken down and carried through those still in position and set up ahead. Since there were no heavy pieces all this work could be done by hand and no carriage was provided. Sidewalls were built in advance of the arch. As in other pressure tunnels, the invert was built first, and a working platform near the springing line was used for concreting the sidewalls and arch. These forms did not produce as smooth a surface as those used in other tunnels, the great number of small plates necessitating

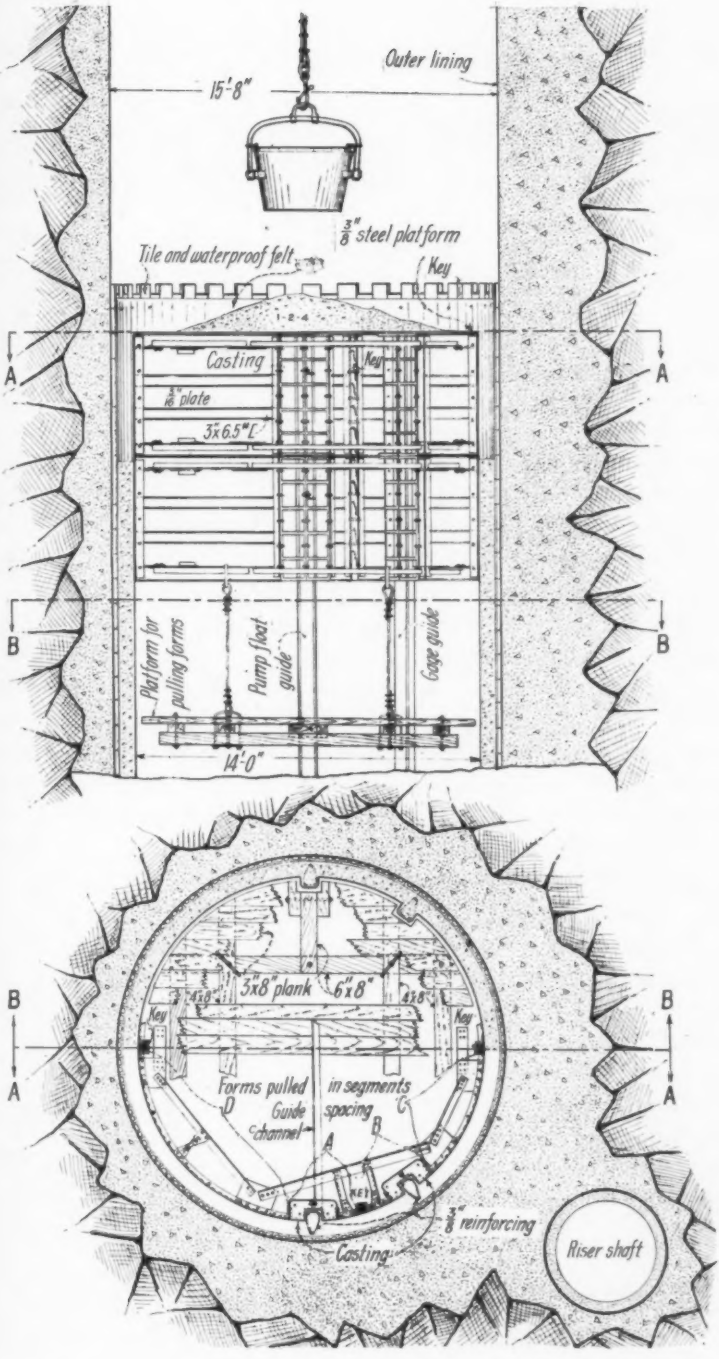


FIG. 50.—METHOD OF PLACING INNER LINING IN SHAFT 21 CITY TUNNEL.

a large number of joints which resulted in some roughness on the concrete surface, and furthermore, it was difficult to hold the plates rigidly enough to prevent irregularities in the concrete surface.

In concreting pressure tunnels it was first attempted to construct short stretches of invert by methods similar to those found successful for cut-and-cover aqueduct, and then follow closely with sidewalls and arch. It soon developed to be more economical and more satisfactory in every way to complete the invert from shaft to shaft before placing any other concrete. For the invert simple forms were used, as shown in Figs. 38 and 39. In some cases the concrete was placed by wheelbarrows, in others dumped from cars on to platforms and shoveled into the forms, and in still others dumped directly from the cars into the forms, the car tracks being supported on timbers across the tunnel at a convenient height about the invert forms. The surface was roughly shaped with shovels as the concrete was deposited and later finished with screens and trowels.

For most of the pressure tunnel work Blaw steel forms were used. In the early seasons, sidewall was built first and the same forms inverted (Fig. 40) for the casting of the arch after a long stretch of sidewall had been completed. As mentioned for the full-circle forms, the early intention with the Blaw forms was to take them apart and re-assemble in moving ahead, but a method was developed for collapsing and moving these forms in larger units, the forms when used for sidewalls being mounted on carriages traveling on beveled wheels on the invert. Screw jacks on the carriages raised and lowered the forms. For arch work the forms, after having been turned over, were mounted on high wooden carriages running on rails at first and later on beveled wheels on the invert.

In later seasons a more economical method of using the forms was developed, known as "trailing" forms (Fig. 41). In this method the invert having been completed, a unit of sidewall forms and a unit of arch forms were kept adjacent to each other in moving ahead so that concrete could be deposited in either of the two during the same concreting period. Then concrete which could not be conveniently used in the arch was deposited in the nearby section of sidewall forms, and it was found that

with a slightly larger gang, under one foreman, a section of side-walls usually could be completed as soon as the adjacent arch could be done, including keying of the arch, with economies all along the line of the concreting operations. Frequently the side-wall forms were filled before the adjacent arch was completely keyed. The steel forms as used for this method of tunnel lining are well shown in Fig. 42.

As for cut-and-cover aqueduct, the earlier pressure tunnel

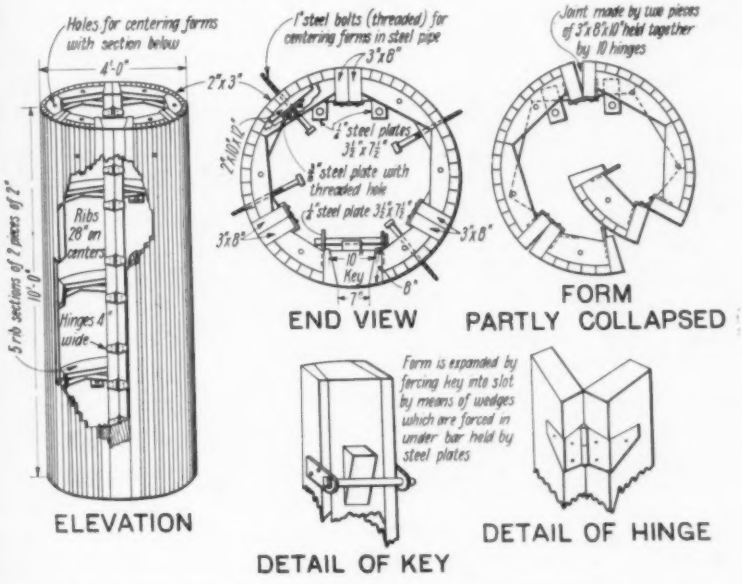

Holes for centering forms with section below
4'-0"
2"x3"
Ribs 26" on centers
Hinges 4" wide
5 rib sections of 2 pieces of 2" 10'-0"
ELEVATION
1" steel bolts (threaded) for centering forms in steel pipe
3"x8"
1" steel plates 3½"x7½"
⅜" steel plate with threaded hole
1" steel plate 3½"x7½"
3"x8"
10" Key
8"
7"
END VIEW
Joint made by two pieces of 3"x8"x10" held together by 10 hinges
FORM PARTLY COLLAPSED
Form is expanded by forcing key into slot by means of wedges which are forced in under bar held by steel plates
DETAIL OF KEY
DETAIL OF HINGE

FIG. 51.—CITY TUNNEL, 4-FT. DIAMETER FORMS FOR LINING STEEL RISER PIPES.

forms were too light in certain parts and had defects of design and workmanship. Later forms for tunnels 15 ft. in diameter (Fig. 43), were made with plates $\frac{3}{16}$ in. thick and had ribs of 6 in. 15-lb. ship channels, spaced 5 ft. apart. At the horizontal diameter there were struts of two 6-in. 8-lb. channels engaging the ends of the ribs through 15 x 18 x $\frac{3}{8}$-in. gusset plates and supporting the working platform. Near each quarter point of each rib there was a vertical post of two 6-in. 8-lb. channels bearing on the horizontal strut through gusset plates and connected to the rib

by gusset plates. These were further stiffened by 3 x 2 x $\frac{1}{4}$-in. angles, extending longitudinally from rib to rib and spaced around the form as indicated in Fig. 43. The longitudinal angles at the crown were 2.5 ft. apart; transversely between them and dividing the spaces between ribs into two equal parts were short 3 x 2 x $\frac{1}{4}$-in. angles to support the 2.5-ft. square key plates. Key plates had a 3 x 5 x $\frac{5}{16}$-in. angle near each edge on the inner side. To move these arch forms they were first collapsed slightly by means of turnbuckles attached to the gusset plates at the bottoms of the verticals and the ends of the horizontals and then lowered by driving out the wedges and operating the screw jacks supporting the forms from the carriage. To permit the collapsing, the gusset plates at the ends of the horizontal members were bolted to them through slotted holes. By the use of these forms very satisfactory tunnel lining with smooth surfaces was obtained.

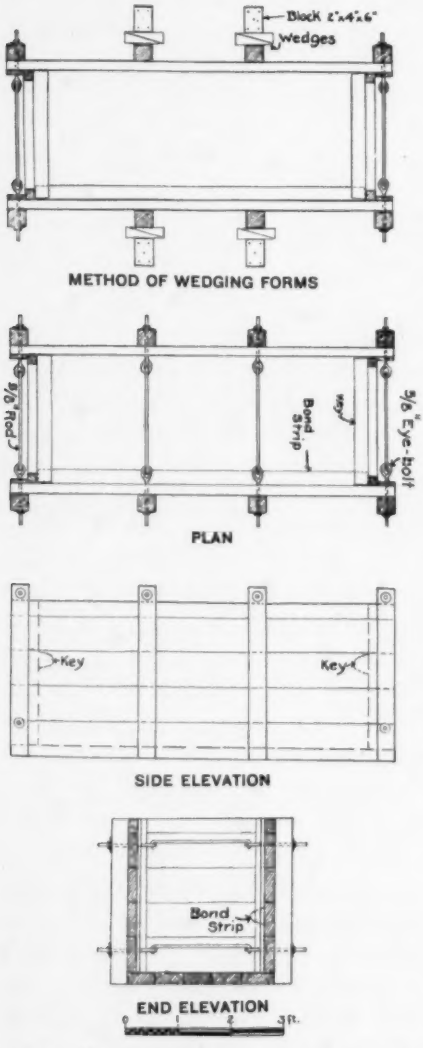


FIG. 52.—TYPICAL FORM FOR CASTING BLOCKS, OLIVE BRIDGE DAM.

An important question in concreting circular tunnels was the length of form which should constitute a unit. The shortest units were long enough to cast 30 ft. of sidewalls or 30 ft. of arch

at a time and the longest units were sufficient for 150 ft. of sidewall or 150 ft. of arch, with the "trailing" forms a length of tunnel lining equivalent to the length of a unit of forms was completed each shift concreting was done. The number of fine cracks in the concrete arch was found to increase rapidly when the units exceeded 40 ft. in length, but this disadvantage was offset by the reduction in the number of joints between successive stretches of concrete. With the longest units of forms it was difficult to cast the sidewalls or the arch monolithically; in other words, to have the concrete delivered and placed rapidly enough through such long forms as to prevent the initial set occurring

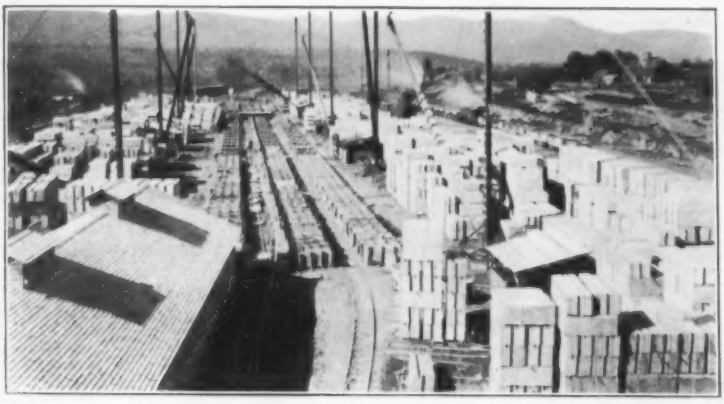


FIG. 53.—CONCRETE BLOCK-YARD SHOWING BLOCKS AND FORMS FOR BLOCKS USED IN THE CONSTRUCTION OF THE OLIVE BRIDGE DAM.

on some surfaces before the forms were filled. This was particularly true where the breakage of the rock varied widely from the required cross-section of the excavation.

Forms and methods used on the 6000 ft. of 12-ft. and 15,000 ft. of 11-ft. diameter tunnel forming the most southerly portion of the City tunnel, extending from lower Manhattan into the heart of Brooklyn, are typical of the highest development reached. A brief description of the forms and methods used at Shaft 19, which is 710 ft. deep, will answer for all this work. There were provided of sidewall and trailing-arch forms two 80-ft. units, two 70-ft. units and one 60-ft. unit, and two inclines for concrete cars

one in the tunnel north of the shaft and one in the south tunnel. The total length of tunnel concreted from this shaft was 6268 ft.

The sidewall and arch forms were carefully designed to give the maximum working room for placing the concrete in the 11 and 12-ft. tunnels. Clearances were so small that the top of the storage-battery locomotive was only 2 to 3 in. from the channel cross brace. The following tabulation shows sequence, time and labor for erecting in the first instance a 70-ft. sidewall form in the tunnel:

12 men on surface for 16 hours to lower forms into tunnel.
12 " in tunnel for 16 hours to carry forms to position.
12 " for 16 hours setting up ribs and plates.
8 " for 12 hours building platforms and sidewall extension.
4 " 8 hours putting in carriage.
3 " 16 hours erecting incline.
2 " 8 hours bolting deck to form.
2 " 8 hours straightening out plates.
Total = 98 man-days of 8 hours.

The arch form was erected in about the same length of time.

Sidewall forms extended from the sides of the invert to about $2\frac{1}{2}$ ft. above the working platform. The joint at the top of each sidewall was made by filling under a 10-in. radial board bolted to the forms and by troweling smooth a horizontal surface from the board to the rock, thus insuring a joint free from laitance. About 5 to 6 ft. of arch key concrete was placed per hour and the keying was usually finished from one to two hours after the completion of the sidewalls. The total time to fill the sidewalls and arch of the 60-ft. form varied from 10 to 25.5 hours, averaging 16.5; for a 70-ft. form from 12 to 21 hours, averaging 16.5; for an 80-ft. form from 11 to 24 hours, averaging $17\frac{3}{4}$. As soon as one form was completely filled, the entire concreting forms moved to another form, which meanwhile had been made ready for concreting by the form gangs. Forms were loosened by turnbuckles about 16 hours after concreting. While forms were being loosened, the stretch of tunnel in front of the forms was thoroughly cleaned.

When ready to advance, the sidewall was lifted on to the

carriage and then pulled ahead by the form hoist, the cable being reeved through two pulley blocks, one attached to the form carriage and the other to a chain fastened to timbers braced from the concrete invert to the rock. The sidewall form was rotated slightly, in some cases 10 in. out of level, as it was pulled ahead. This was easily remedied by jacking the low side up at both ends of the form.

The arch form was pulled in with turnbuckles, lowered on to the jacks of the carriage, then pulled ahead as above described for the sidewall form. The arch form was guided by side rollers

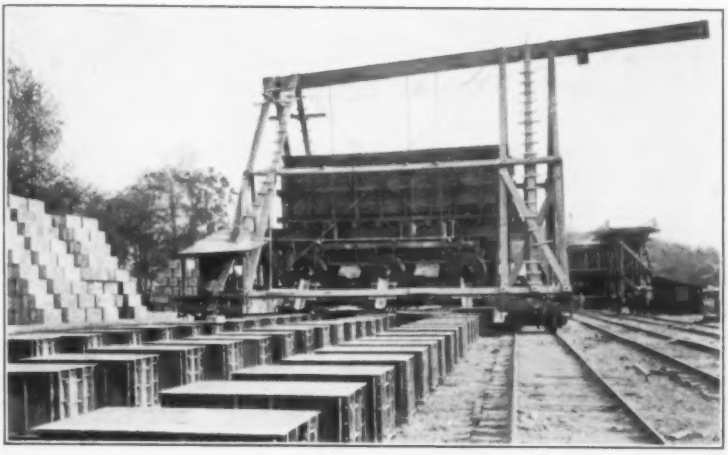


FIG. 54.—TRAVELER CARRYING THREE CONCRETE MIXERS AND STEEL FORMS FOR CONCRETE BLOCKS USED IN THE CONSTRUCTION OF THE KENSICO DAM.

bearing against the concrete, as it was found impossible otherwise to prevent the form from rolling sideways. Moving sidewall and arch forms usually took six men about eight hours. After the forms had been moved, it took eight hours more to jack them back to line and grade, build bulkheads, clean out behind the forms, grease the forms, and otherwise make them ready for new concrete, but, in some cases, the entire operation has been completed in twelve hours.

Forms were cleaned by scraping with a chisel-edged tool 2 in. wide, and were coated with a mixture of grease and oil just

prior to concreting. The forms were stiffened and held rigidly to line partly by the carriage but mostly by the platform, the planks of which were bolted or nailed to the ribs. For curves in the aqueduct alignment, the requisite degree of curvature was secured by inserting panels of tapered steel plates between 10-ft. sections of the form. This, of course, practically necessitated dismantling and reassembling the form, but it worked out satisfactorily and gave good results. It took about four shifts, breaking a 60-ft. form into 15-ft. lengths, to go around a 5° curve, whereas it took about six to eight shifts to set up the form around a 90° curve.

SHAFT FORMS.

Each pressure tunnel, with a few exceptions, has a downtake shaft at its upstream end and an uptake shaft at its downstream end, connecting with the adjacent grade aqueduct, and an intermediate drainage, or pumping shaft. There are also a few intermediate step shafts in some of the tunnels, connecting higher with lower levels of tunnel. All these shafts are circular in cross-section. In the City pressure tunnel, 22 of the 24 shafts are used for connections to the street pipes and one for drainage purposes alone. One of the 22 shafts is a combined drainage and connection shaft, and two others are rectangular, containing special section valves, dividing the tunnel into three parts. Twenty-one of the shafts are circular in section and were lined with concrete as they were sunk.

For concreting circular shafts steel forms were used, built in sections 5 ft. high, divided into quadrants. They were commonly of $\frac{1}{4}$-in. plates with ribs of 3 x 2 x $\frac{1}{4}$-in. angle irons and internally trussed. The best method was found to be concreting the shafts from the top downward, as less trouble was experienced with the water, which, even in small quantities, was bothersome when concreting from the bottom upward. Some shaft forms are shown in Figs. 47 and 48. The working platform was usually supported on top of the forms after they had been placed in position, and the concrete was lowered in bottom-dumping buckets on to the platform and shoveled into the space back of the forms.

At the bottom of each downtake and uptake shaft is a quarter-bend, connecting the shaft to the tunnel. The first

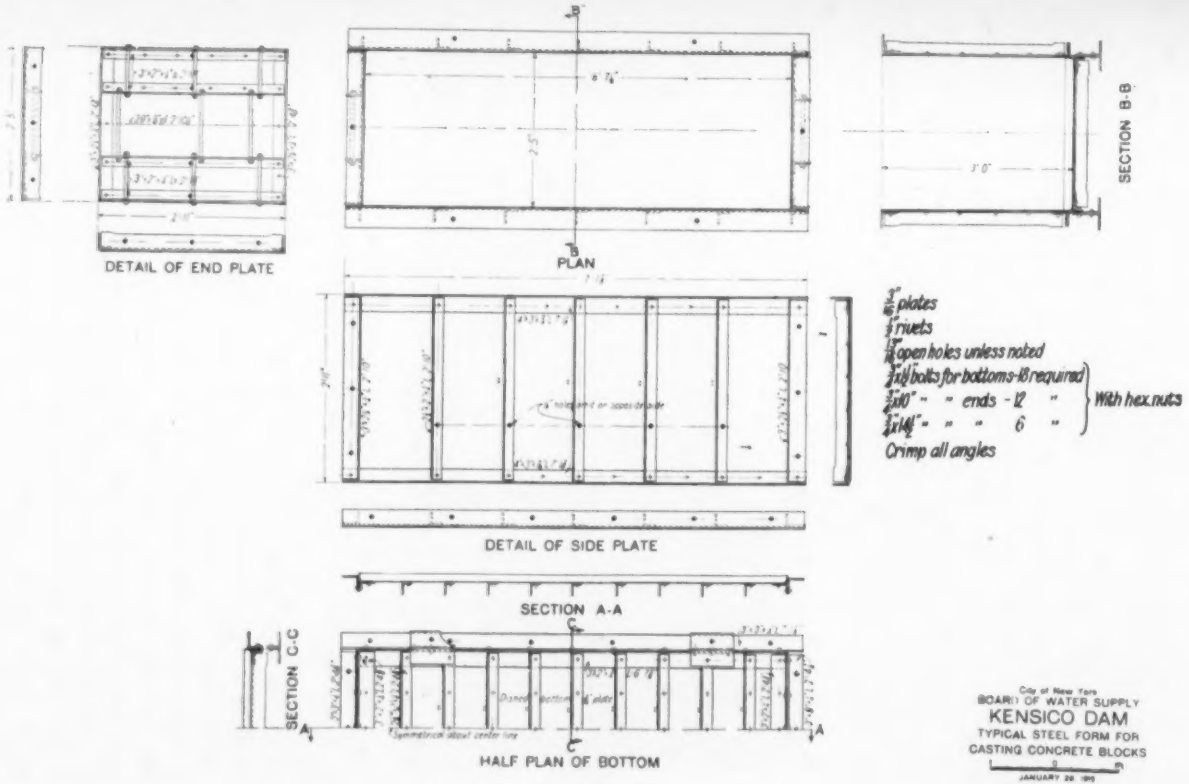

DETAIL OF END PLATE
PLAN
SECTION B-B
DETAIL OF SIDE PLATE
SECTION A-A
SECTION C-C
HALF PLAN OF BOTTOM
plates
rivets
open holes unless noted
bolts for bottoms-18 required
" " ends - 12 "
" " " 6 "
With hex.nuts
Crimp all angles
City of New York
BOARD OF WATER SUPPLY
KENSICO DAM
TYPICAL STEEL FORM FOR
CASTING CONCRETE BLOCKS
JANUARY 20 1915

FIG. 55.

wooden quarter-bend form (for Rondout pressure tunnel) was made with elliptical ribs of 2-in. white oak, covered with 1 x 1-in. white ash strips laid on in two thicknesses. This form was cut on the longitudinal and transverse median planes and on the curved surface through the axis into eight parts for convenience in handling. It was used four times (twice in the Wallkill pressure tunnel), but after each use required extensive repairs. Another form for a quarter-bend (one of several in the City tunnel) is shown clearly in Fig. 49.

Forms for Drainage Shafts.—Drainage shafts of pressure tunnels have an outer concrete lining against the rock, a terra-

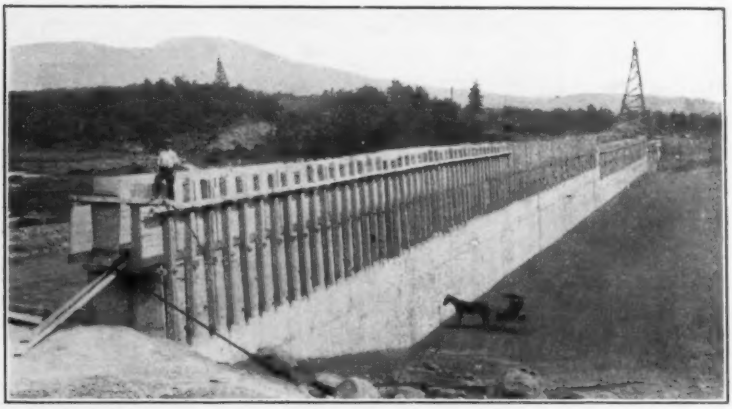


FIG. 56.—WOODEN FORMS USED IN THE CONSTRUCTION OF THE CONCRETE CORE-WALLS FOR THE EARTH DIKES OF ASHOKAN RESERVOIR.

cotta tile interlining with vertical grooves to collect such slight seepage as may penetrate the outer lining, and a smooth concrete inner lining which carries two pairs of vertical reinforced concrete guides. One pair of guides is for the cylindrical steel float containing the pumping apparatus used for unwatering the shaft and tunnel and the second pair is for the cage, or elevator, for service between the float and the head-house at the top of the shaft. It is very important that these guides, throughout the depth of the shaft, should be smooth, accurate in shape, true to line and accurately spaced. In most of the drainage shafts much difficulty was experienced because forms and methods were

inadequate, and although much effort was expended upon them, some of the guides were unsatisfactory, until corrected.

For placing the concrete inner lining of Shaft 21, one of the drainage shafts for the City tunnel, 750 ft. deep, nine 5-ft. sections of steel forms, a total of 45 lin. ft., were provided. These forms (Fig. 50), were made by the Blaw Company and were equipped with special iron castings for molding the four concrete float and cage guides. Previous to use in the shaft, each 5-ft. section was set up, measurements made, and hardwood keys fitted in so as to give the proper distances between the different guides. In order to obviate the possibility of the diametrically

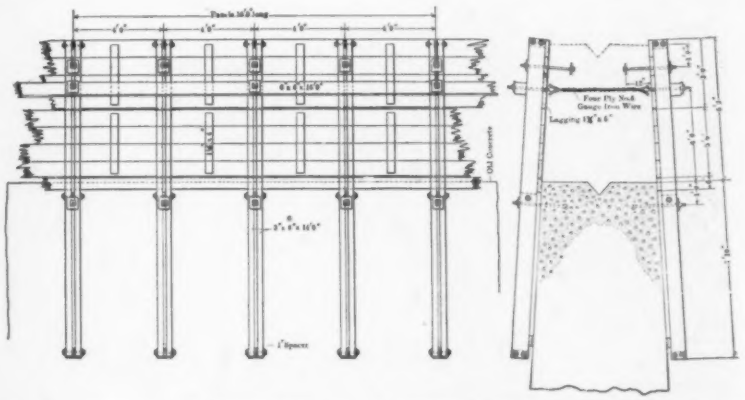


FIG. 57.—DETAILS OF CONSTRUCTION OF CANTILEVER FORM FOR CORE WALLS AND ASHOKAN RESERVOIR METHOD OF FASTENING AND WIRING.

opposite float guides coming too close together, and thus encroaching on the minimum clearance, two 4 x 4-in. angles were bolted from the back of one guide form to the corresponding side of the opposite form, one near the top and the other near the base of each 5-ft. casting.

Work was prosecuted continuously through three shifts, the usual cycle being as follows:

1. Set tile and waterproofing, $1\frac{1}{2}$ hours.
2. Set 5-ft. section of forms, $3\frac{1}{2}$ hours.
3. Concreting, 1 hour.

When all nine sections of form had been used, the lower six sec-

tions were pulled (in about 12 hours) and taken to the top of the shaft. Then the seventh section was pulled, immediately set up again on top of the two sections left in place, and made ready for concreting. The next six 5-ft. forms to be used were lowered from the surface, as needed, and then forms were again pulled as before. When pulling forms, the men worked from a substantial timber platform booked to the forms above those being taken out. In setting the forms the float guides were aligned under

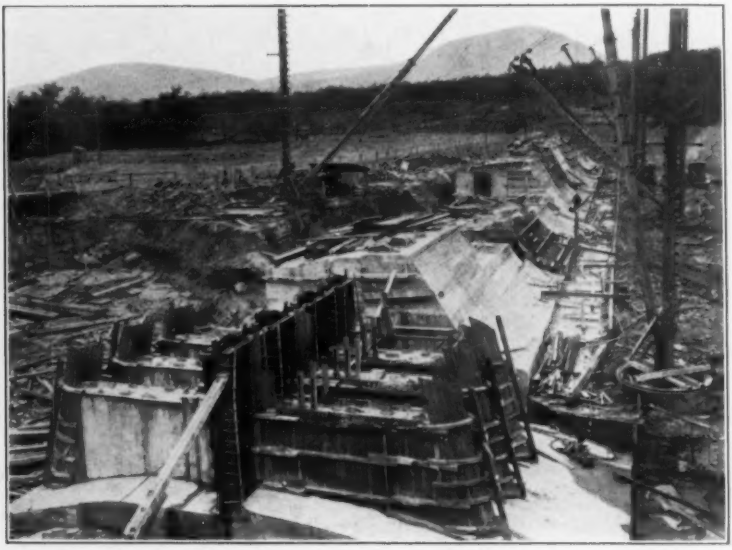


FIG. 58.—WOODEN FORMS FOR DIVIDING WEIR AND FOR THE WALLS OF THE DIVIDING WEIR GATE-HOUSE, BETWEEN THE EAST AND WEST BASINS OF ASHOKAN RESERVOIR. THE SLUICE GATES ARE IN POSITION.

plumb-bob wires and the cage guides then brought to their proper position by measuring from the float guides. These forms could be satisfactorily held to line by the use of short wooden braces between the front of the form and the back of the tile. No interior bracing was necessary and it is probably due to this fact that forms remained true to line and level so that very little shimming under the forms was necessary and practically no cracked guides resulted.

Riser Lining Forms.—In the City tunnel, connections to the street mains were made by means of steel riser pipes in the shafts, imbedded in the shaft concrete and lined with concrete. For lining these steel risers, forms shown in Figs. 51 were used. The forms used in placing the concrete inner lining in the steel risers were of wood, built in sections 10 ft. long. They were composed of four vertical leaves and a key, the leaves being joined together with strap hinges, permitting the form, after the removal of the key, to be folded.

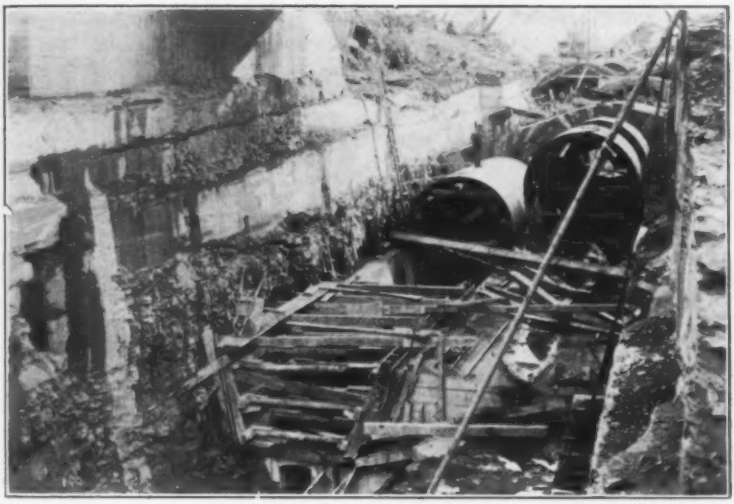


FIG. 59.—METAL COVERED WOODEN FORMS FOR SPECIAL AQUEDUCTS LEADING FROM THE LOWER GATE-HOUSE OF THE ASHOKAN RESERVOIR TO THE SCREEN CHAMBER.

Number of Linear Feet of Aqueduct Forms Used on Individual Contracts.—The number of linear feet of forms used by contractors varied with the length and continuity of the particular type of aqueduct involved. For cut-and-cover work on lengths of aqueduct of 2000 to 5000 ft., from 30 to 35 ft. of forms were used for each thousand feet of aqueduct under construction. For lengths of 10,000 to 25,000 ft., 20 to 10 ft. of forms per thousand feet of aqueduct were used. In grade tunnels there were used about 15 ft. of forms per thousand feet of tunnel. In pressure

tunnels there were used about 20 ft. of forms for each thousand feet of tunnel, but in one case, where a maximum rate of progress was desired, this length per thousand feet was doubled.

Cost of Forms.—Blaw forms were usually leased by the contractor until the completion of his work. Ransome forms were bought outright. Wooden forms were built by the contractors themselves. In one case the contractor built his own steel forms,

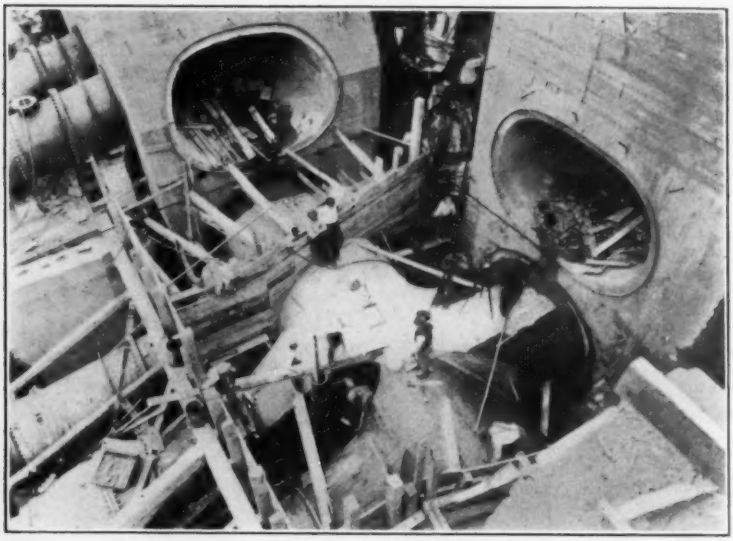


FIG. 60.—HEADWORKS OF CATSKILL AQUEDUCT. FORMS FOR BELL-MOUTHS FOR INTAKES FROM THE LOWER PRESSURE AQUEDUCT TO 48-IN. CONTROL VALVES IN LOWER GATE-CHAMBER. UPPER PRESSURE AQUEDUCT ALSO SHOWN, WITH GAP BETWEEN ITS BRANCHES REMAINING TO BE CONSTRUCTED.

which, although somewhat more expensive, proved to be the best and most efficient in all respects. Cut-and-cover forms, outside and inside, cost from $55 to $100 per lin. ft. of form, the wide variation being due to the differences in type, method of purchase, weight of metal involved, and kind of lagging for outside form, whether steel or wood. In some cases the contractors were able to purchase second-hand equipment from other contractors whose work had been completed. Pressure tunnel forms

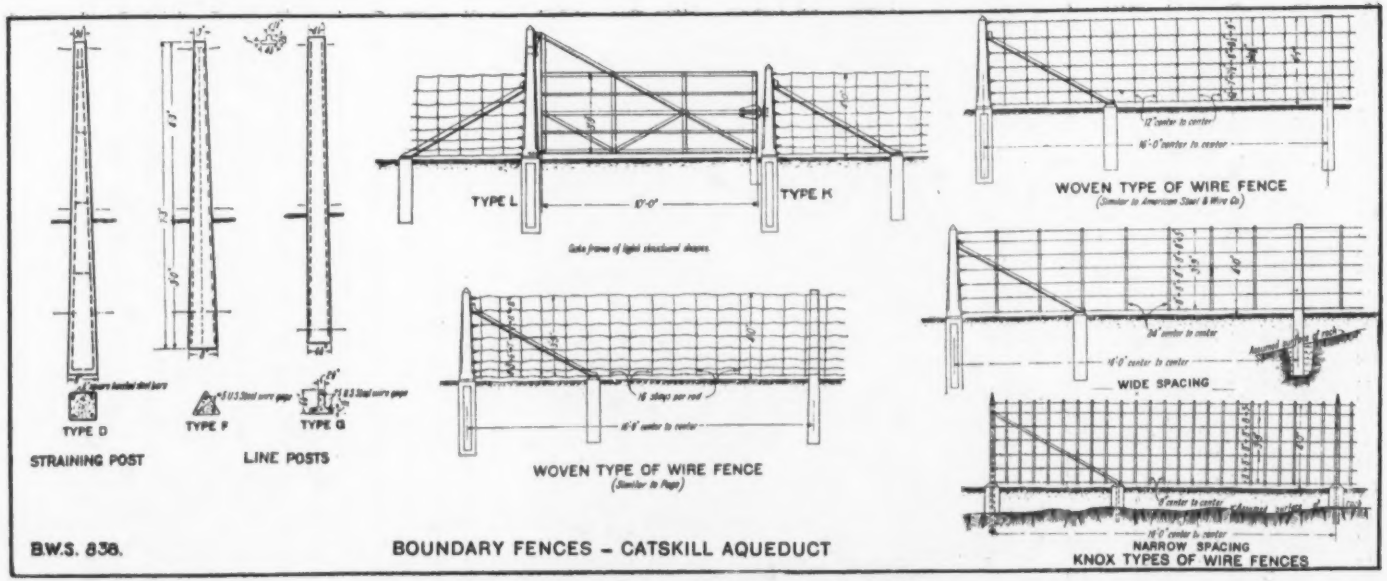


FIG. 61.—REINFORCED CONCRETE FENCE POSTS.

cost from $35 to $55 per lin. ft. (full section), depending upon size, type and weight of metal. The cost of installation of these forms was large, varying from $20 to $40 per lin. ft. This installation cost included the carriages for moving the forms, inclines for approaches to the forms and the setting up of the forms in the tunnel for the first time.

FORMS FOR CONCRETE BLOCKS AND COREWALLS.

Face Blocks for Olive Bridge Dam.—In the construction of the Olive Bridge dam, 56,000 cu. yds. of concrete blocks were

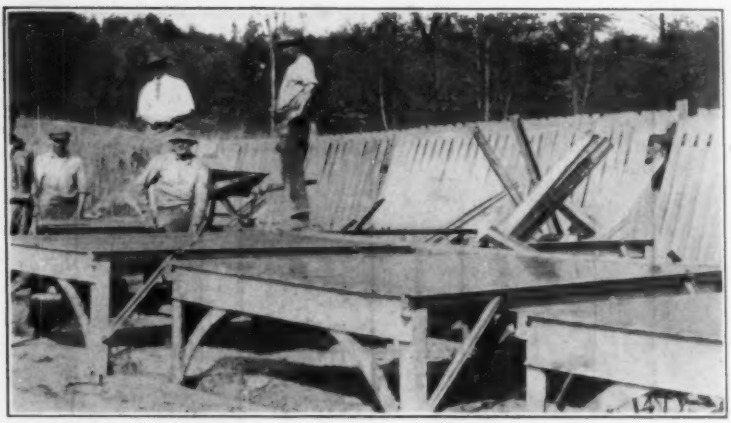


FIG. 62.—SKELETON STEEL TABLE SUPPORTING STEEL MOLDS FOR CASTING REINFORCED CONCRETE FENCE POSTS. MOLDS ARE SHOWN FILLED WITH CONCRETE.

used on the upstream and downstream faces and in the expansion joints. The essential features of the wooden forms used for these blocks are shown in Fig. 52. The concrete was dumped on to a movable platform which was so arranged as to travel up and down on tracks laid in the concrete block yard (see Fig. 53). This platform passed over two middle rows of forms and alongside two outer rows. From the platform the concrete was shoveled directly into the forms. The side of the form against which the exposed face of the block was cast, was lined with sheet metal. In the case of the three larger batters of the downstream face,

the forms were arranged with exposed face on a side, the top of the block being down during casting. The upper batters of the downstream face and all the blocks of the upstream face of the dam were cast with the exposed face of the block down.

Face Blocks for Kensico Dam.—The upstream face and the expansion joints of Kensico dam are faced with concrete blocks, requiring a total of about 60,000 cu. yds. of concrete. The concrete for these blocks was mixed on a traveler (see Fig. 54) spanning three rows of forms, the main features of which are

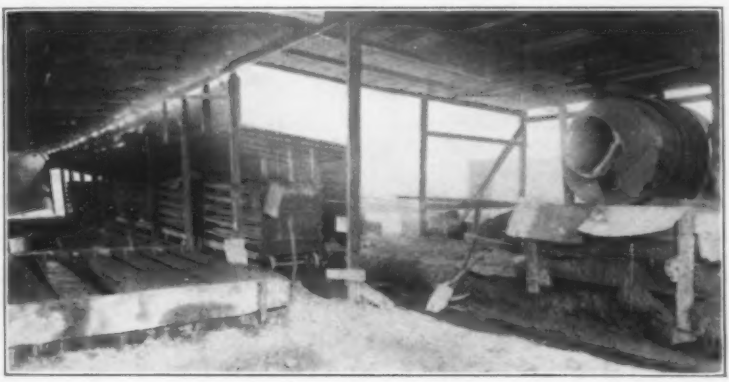


FIG. 63.—FORMS FOR CASTING REINFORCED CONCRETE FENCE POSTS. SIX MOLDS PLACED SIDE BY SIDE MADE UP A SET; FIVE OR SIX OF THESE SETS WITH GALVANIZED IRON SHEETS BETWEEN WERE MOUNTED ON A CAR. CARS ARE JOGGLED TO REMOVE AIR AND THUS PREVENT BLOW HOLES AND OTHER BLEMISHES.

shown in Fig. 55. These blocks were all cast with exposed face down. The forms were entirely of steel, and consisted of a bottom or bedplate and four sides fastened together by bolts through flanges. These forms have proved to be rigid and tight, and have given no trouble from bulging or distortion.

Forms for Dike Corewalls.—In the construction of the Ashokan reservoir, about 5¼ miles of earth dikes were built. These dikes consisted of rolled earth embankments with concrete corewalls 4 ft. wide on top, each face of the corewall having a batter of 1 in 20. The maximum width of corewall was about 14 ft. and the maximum height about 100 ft. As soon as the work was

well under way, the following described type of form, for the construction of corewalls, was evolved. This form obviated the necessity for long raking braces. The corewall was usually built in courses 6 ft. high and 75 to 100 ft. long, depending upon the quantity of concrete which could be placed in a single 8-hour day. The forms used are as shown on Figs. 56 and 57. Pairs of vertical 3 x 3-in. x 14-ft. timbers, spaced 1 in. apart, the pairs being 4 ft. center to center, formed the uprights. For the top 6½ ft. of these uprights 1¼ x 6-in. lagging was used. The uprights were held in position by bolts imbedded in the concrete previously laid. In each 6-ft. lift of concrete a pair of bolts was concreted. The required width of wall was maintained by twisted wires attached to bolts inserted into the uprights, as shown by the illustration. After concreting, the form was moved upward, the bolts fitting in the slots between the 3 x 8-in. uprights.

FORMS FOR GATE-CHAMBERS AND OTHER SPECIAL STRUCTURES.

Of gate-chambers, screen-chambers, siphon-chambers and other special structures, there are several score along the Catskill aqueduct. Owing to the large quantities of water to be handled most of these are necessarily of large size and the needs in several cases led to some difficult concrete form work. Only a few examples can be included in this paper. They are shown in Figs. 58, 59 and 60. In general, forms for flat surfaces were either built up in place of 2 x 4-in. or larger timbers and about 1 or 2-in. lagging, or were made in panels which could be removed and used again. For the curved faces of overflow weirs, some bridge piers and similar structures, curved wooden forms in the panels were used. In many cases forms for walls were secured to each other or to the concrete previously placed by means of twisted wires, braces or blocks being used to hold the forms apart. After the removal of the forms the wires were cut off a short distance back of the concrete surface and the cavities filled with mortar. In many places rods were used for holding the forms instead of wires. The central and longer portions of such rods were left in the concrete, but at each end these portions had screw couplings into which the bolts projecting through the forms were taken off and the small holes in the concrete pointed full of mortar. In the gate-houses at the reservoirs and particularly in the special aque-

ducts connecting the gate-houses, screen-chamber and aeration fountain at Ashokan reservoir, some unusual and complicated conduits, from the form-maker's point of view, were required. A suggestion of the character of this form work can be obtained from Figs. 59 and 60. For these special conduits some of the wooden forms were made in convenient lengths which could be used repeatedly and were covered with galvanized sheet steel of No. 23 gage. In most other respects there were no unusual features in the forms for these special structures excepting their size and the necessity for obtaining smooth surfaces on the con-

FIG. 64.—FORMS FOR THE GIRDERS AND FLOOR-BEAMS OF A REINFORCED CONCRETE GIRDER BRIDGE, SHOWING SOME OF THE REINFORCING STEEL.

crete exposed to flowing water so as to minimize hydraulic losses and facilitate cleaning.

REINFORCED CONCRETE FENCE POST MOLDS.

About 150 miles of galvanized steel wire fencing with concrete posts were built along the Catskill aqueduct between the northern limits of Ashokan reservoir and the northern boundary line of New York City. Fig. 61 shows the typical cross-sections of posts used.

There were two types of steel forms for casting line posts. In the first type (Fig. 62), the individual forms were assembled, generally ten at a time, and placed horizontally on a low skeleton steel table. Each form was of sheet metal about $\frac{1}{16}$ in. thick rolled to the desired shape. They were equipped with tightly fitting steel removable ends. After the molds had been filled with liquid concrete, the table was joggled to expel air bubbles, thus insuring a smooth surface free from blow holes and other blemishes. In the second type (Fig. 63), the table was not used,

FIG. 65.—TRAVER HOLLOW BRIDGE, ASHOKAN RESERVOIR, SHOWING SOME OF THE FALSE-WORK AND FORMS FOR THE COLUMNS AND FLOOR SYSTEM, ALSO THE COMPLETED THREE-HINGE ARCH RIBS OF 200-FT. SPAN.

its place being taken by a small steel car the length of the molds and wide enough to hold six side by side. After this set of six molds had been filled with concrete, a second set was placed on the car above the first, and so on until five or six tiers were in place. Between sets a horizontal sheet of galvanized iron was interposed to prevent the drip from the forms above from ruining the exposed surface of the posts below. Joggling was accomplished by running the car holding the forms on an uneven track. These molds were also of sheet metal about $\frac{1}{16}$ in. thick. They had no fixed ends, the closure being made by means of a cast-iron door

which was permanently fixed to the car. This door swung in, holding the molds in place as well as forming the ends for them.

The heavier straining and gate posts were cast in sheet metal forms laid horizontally side by side in panels, see Fig. 63. Each individual form had cast-steel ends held in place by a plank running across the end of the tier of forms.

FORMS FOR REINFORCED CONCRETE BRIDGES.

In connection with the highways constructed around Ashokan and Kensico reservoirs two types of reinforced concrete bridges,

FIG. 66.—ASHOKAN BRIDGE. STEEL FALSE-WORK SUPPORTED ON WOODEN BENTS. WOODEN LAGGING AND THE CONCRETE ARCH RIBS ARE SHOWN, ALSO AT THE LEFT A GATE-CHAMBER FORMING ONE ABUTMENT OF THE BRIDGE.

girder and arch, were built. There are six girder bridges with spans from 25 to 40 ft. and eight arch bridges with spans of 40 to 200 ft. Forms for the girders and floor beams of a girder bridge are shown in the course of construction in Fig. 64. In the arch bridges each span consists of two reinforced concrete ribs, braced laterally, supporting columns which in turn support the bridge floor. With one exception, the arch false-work was of wood. Fig. 65 shows this type of bridge for Traver Hollow with the wooden false-work mostly removed. Fig. 66 shows the centering and some of the forms for five of the fifteen arches of

Ashokan bridge, over the dividing weir between the two basins of Ashokan reservoir, with steel false-work supported on wooden bents and the concrete piers. The arch ribs were cast on plank lagging attached to the steel false-work.

Much information concerning forms and methods in addition to the statements in the text of this paper can be gotten from study of the illustrations. In preparing this description of the forms used for concrete on the Catskill waterworks, the author has received substantial aid from a number of engineers on the staff of the Board of Water Supply and from several of the contractors' engineers. Mention should be made in particular of the assistance rendered by Department Engineer Ralph N. Wheeler, Division Engineers James F. Sanborn and William W. Peabody, and Assistant Engineers H. Goldberg, M. E. Zipser and Charles Goodman, also Messrs. Lazarus White and Dean G. Edwards, formerly division engineer and assistant engineer, respectively.

Mr. J. Waldo Smith has been Chief Engineer of the Catskill waterworks from their inception. Most of the construction mentioned has been done under the direction of Messrs. Robert Ridgway, Carleton E. Davis, Merritt H. Smith, Ralph N. Wheeler, Frank E. Winsor, George G. Honess, Walter E. Spear and Thaddeus Merriman, as Department Engineers. The first three mentioned left the staff of the Board of Water Supply before the completion of the work. The designs were prepared under the immediate supervision of Messrs. Thomas H. Wiggin, Fred P. Moore and Charles E. Gregory, as Designing Engineers, the last named having left the staff before the designs were completed.

If the preceding pages should fall under the eyes of any persons formerly or now connected with the work as engineers, contractors, manufacturers or otherwise, who can furnish additional information or correct any inadvertent misstatements, their assistance in preparing a final, complete and accurate statement concerning forms used in the construction of the Catskill water system, will be much appreciated by the author.